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Small Craft Harbours

Ports pour petits bateaux

WAVE CLIMATE STUDIES

FOR

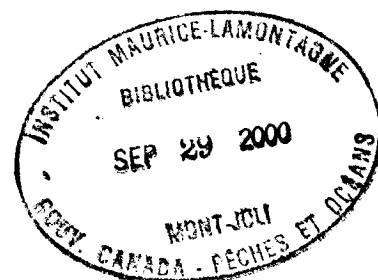
SMALL CRAFT MARINAS

IN THE

PACIFIC REGION

GC
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W383

WAVE CLIMATE STUDIES
FOR
SMALL CRAFT MARINAS
IN THE
PACIFIC OCEAN



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ABSTRACT

Small Craft Harbours (SCH) undertook a study to develop a simple methodology in estimating the level of **wave agitation** experienced in small craft marinas. The analysis dealt mainly with short-period (≤ 6 sec) wind generated waves and had excluded the effects of surges, tides and other long period waves. The **Linear Wave Theory** and **SMB Wave Hindcasting** procedures were applied in the analysis; **refraction, shoaling, and diffraction** analysis have been included. The first part of this report will provide the underlying principles of Coastal Engineering while the second part will outline the analyst's methodology as well as his assumptions.

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INTRODUCTION

The Small Craft Harbours (SCH) Branch operates some 220 harbour facilities used by commercial fishing vessels, pleasure craft and other commercial vessels. One of the main objectives of the Branch is to set standards of accommodation and to ensure proper maintenance of harbours. SCH must provide adequate wave protection, berthage, water depth, launching facilities and other harbour infrastructure to satisfy the needs of local users.

To ensure adequate shelter for vessels, SCH undertook a series of wave climate studies to determine the existing level of wave agitation in the Branch's small craft marinas. The analyst chose a simplified analytical model to get a good first estimate of wave condition at the harbour facilities. The simple analytical procedure was set up so that a microcomputer could be used to perform most of the computations involved in the analysis. A detailed wave climate analysis that requires even more extensive computational tools was not justified due to the existing constraint in resources.

The level of wave agitation for each harbour site will become a permanent part of SCH's Pacific Regional Inventory and will be used for planning, operation and maintenance purposes.

All the analytical and computational work was done in SCH's office in Vancouver, B.C. The analytical results were then sent to Atmospheric Environment Service (AES) in Toronto to engage in their Meteorological Data Processing Program.

2. Fundamentals in Wave Climate Analysis

The principles of coastal engineering summarized here were applied in this study.

2.1 Linear Wave Theory

Waves could be classified as either sea or swells. Sea waves are still under the influence of the generating wind while swells propagate across the water surface free of any significant influence from the wind. In SCH's analysis, sea waves between 2 to 6 seconds were studied.

The **Small Amplitude** or **Linear Wave Theory** is the simplest and generally most useful theory in coastal engineering. It is governed by a set of equations that adequately describe the kinematic and dynamic properties of surface gravity waves; the theory predicts these properties within useful limits in most practical circumstances.

The wave theory was derived under the basis of a set of assumptions: (Ref 10).

- i) Water is homogeneous, incompressible, and surface tension forces are negligible.
- ii) no shear stress at air-sea interface or at the bottom, i.e. flow is irrotational.
- iii) bottom is not moving and is impermeable; and horizontal bottom is not adding, removing, or reflecting wave energy from the flow.
- iv) pressure along air-sea interface is constant; no wind pressures exist; and hydrostatic pressure gradient due to surface elevation differences can be ignored.
- v) wave amplitude is small compared to wavelength and water depth.

The most fundamental description of a simple sinusoidal wave is by its length L , its height H , its period T , and its depth d . (Fig-2-1). The speed at which a wave propagates is known as the wave celerity C

$$C = \frac{L}{T} \quad (2-1)$$

Another relationship for celerity takes the form

$$C = \frac{gT}{2\pi} \tanh \left(\frac{2\pi d}{L} \right) \quad (2-2)$$

Alternate form of equation 2-2 relating wavelength is

$$L = \frac{gT^2}{2\pi} \tanh \left(\frac{2\pi d}{L} \right) \quad (2-3)$$

Waves can further be broken down into several groups, classified by the depth of water in which they travel.

i) Deep water waves

$$d/L > 0.5$$

for great depths,
equation 2-2 then becomes

$$C_o = \frac{gT}{2\pi} \quad (2-4)$$

ii) Transitional water waves

$$0.5 > d/L > 0.05$$

equation 2-2 applies

$$C = \frac{gT}{2\pi} \tanh \left(\frac{2\pi d}{L} \right) \quad (2-2)$$

iii) Shallow water waves

$$d/L > 0.05 \quad C = \sqrt{gd} \quad (2-5)$$

2.1.1 Wave Refraction and Shoaling

Wave celerity depends on the depth of water in which the wave propagates. The decrease in depth causes a decrease in wave celerity, which causes a subsequent decrease in wavelength. The variation in wave velocity occurs along the crest of a wave moving at an angle to underwater contours

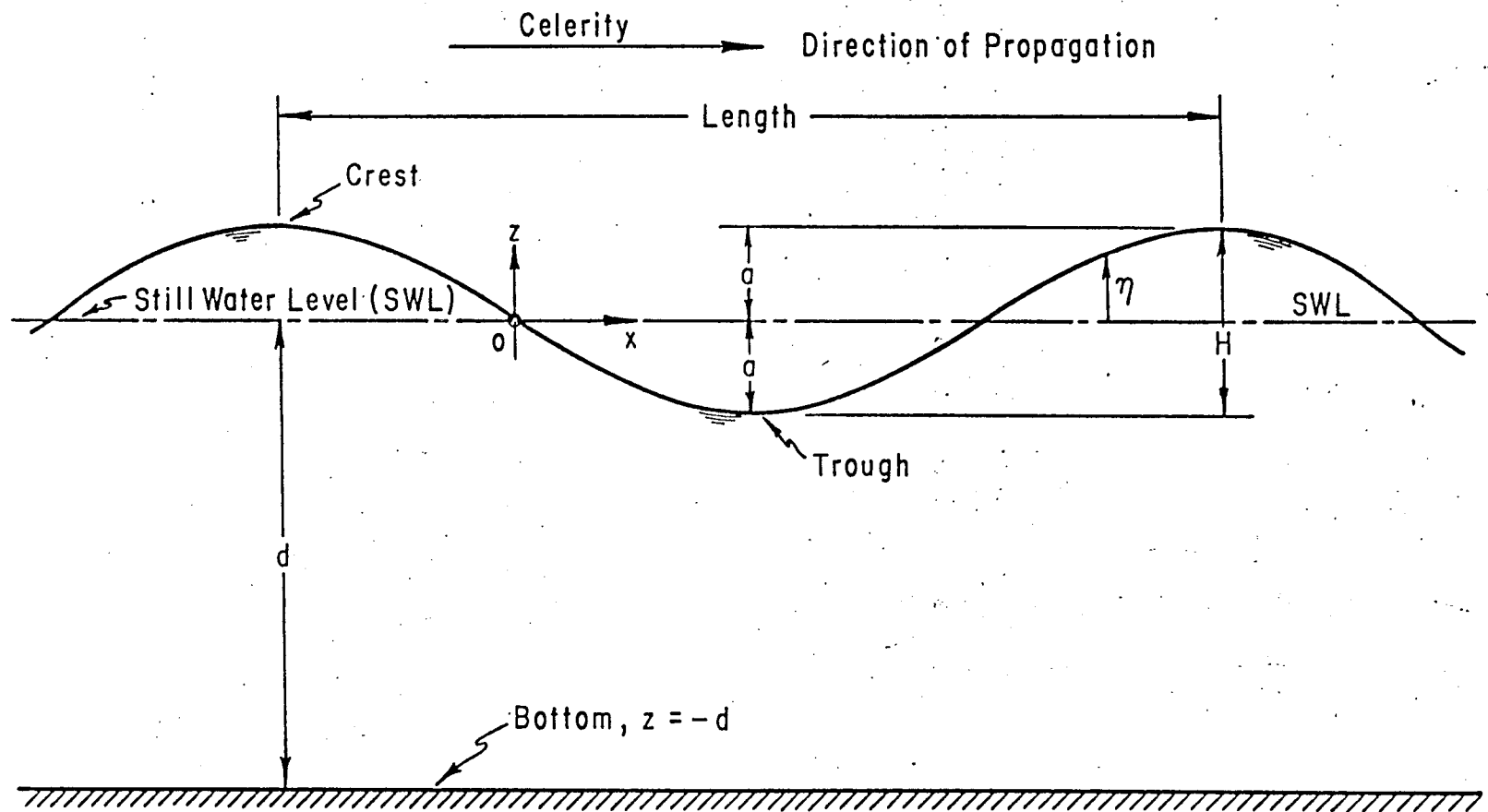


Figure 2-1 Definition of Terms - Elementary, Sinusoidal, Progressive Wave

because waves travel faster in deeper water than in shallower water. The difference in speed causes the wave crest to bend toward alignment with the contours. The bending effect, known as **Refraction by Bathymetry**, will lead to change in the in-coming wave height. (Fig 2-2 to 2-4).

Refraction can also be caused by currents or any other phenomenon that causes one part of a wave to travel slower or faster than another part. However, we are only concerned with refraction by bathymetry here.

The change of direction of a wave orthogonal as it passes over relatively simple hydrography may be approximated by Snell's law: (Fig 2-5 & 2-6).

$$\sin \alpha_2 = \left(\frac{C_2}{C_1} \right) \sin \alpha_1 \quad (2-6)$$

α_1 and α_2 are the respective angles a wave crest make with the first and second bottom contour. C_1 and C_2 are the wave celerities at the depth of the first and second contour.

Snell's law is based on a set of assumptions: (Ref-13)

- i) wave energy between rays or orthogonals remains constant
- ii) wave direction is in the orthogonal's direction
- iii) changes in bottom topography are gradual
- iv) waves have constant period and small amplitude and are monochromatic

Total energy in a wave per unit crest width is:

$$E = \frac{\rho g H^2 L}{8} \quad (2-7)$$

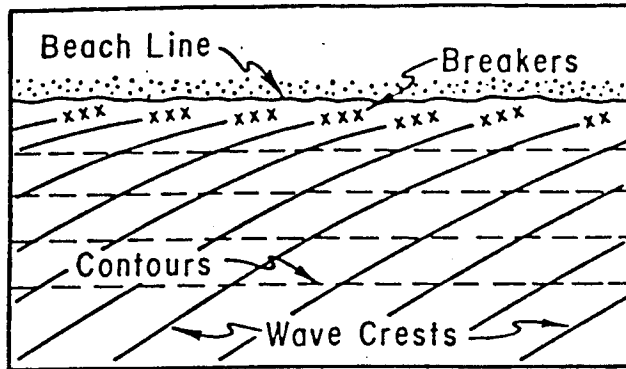
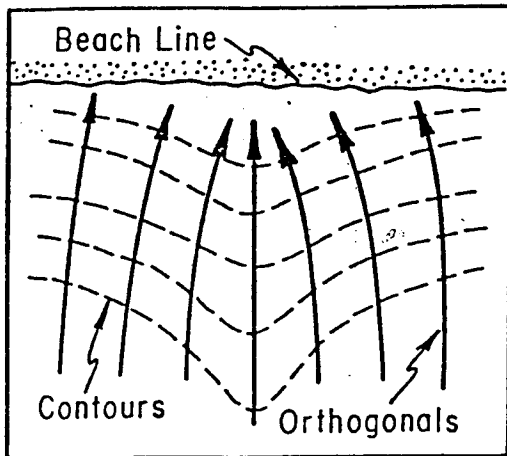
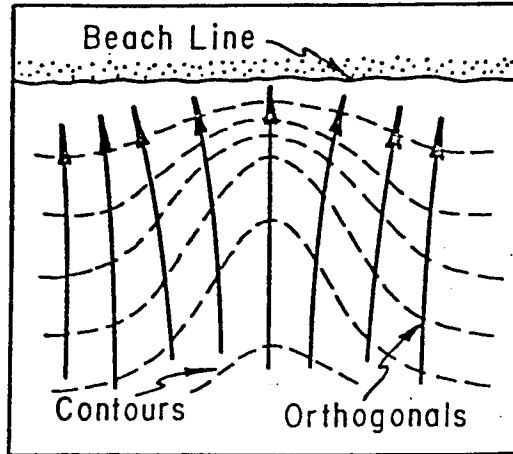


Figure 2-2 Refraction Along a Straight Beach with Parallel Bottom Contours



(a)



(b)

Figure 2-3 Refraction by a Submarine Ridge (a) and Submarine Canyon (b)

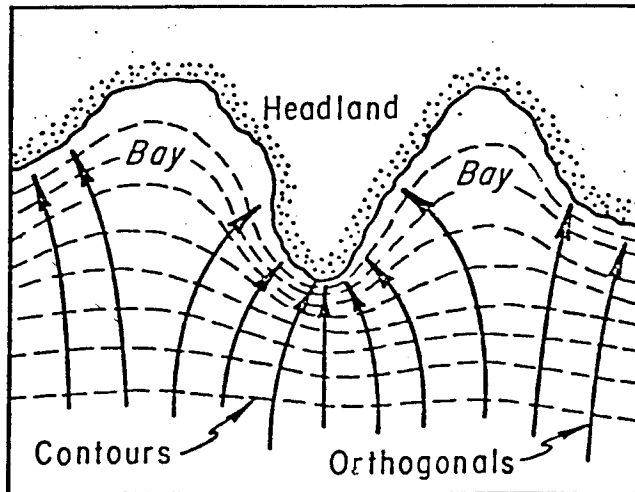


Figure 2-4 Refraction Along an Irregular Shoreline

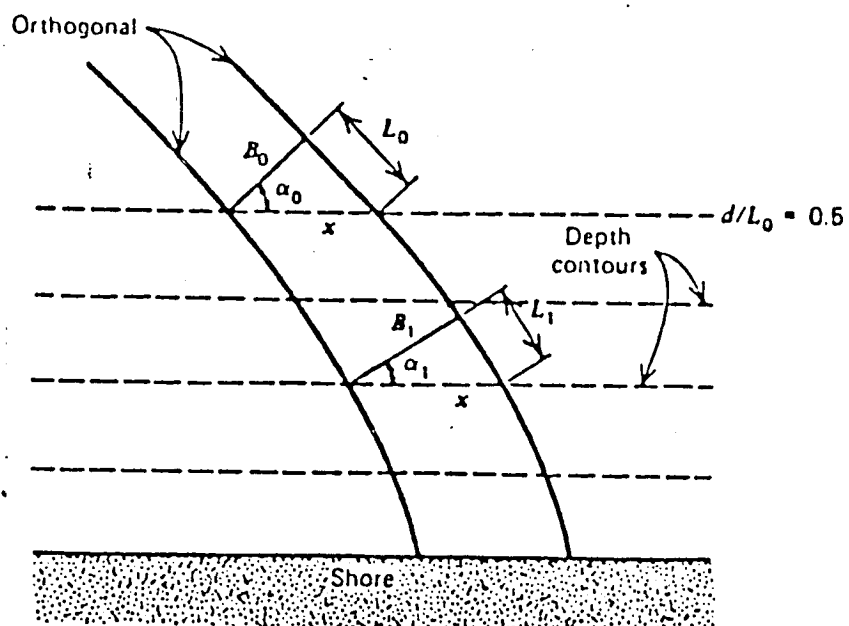


Fig 2-5 Wave refraction over straight parallel contours.

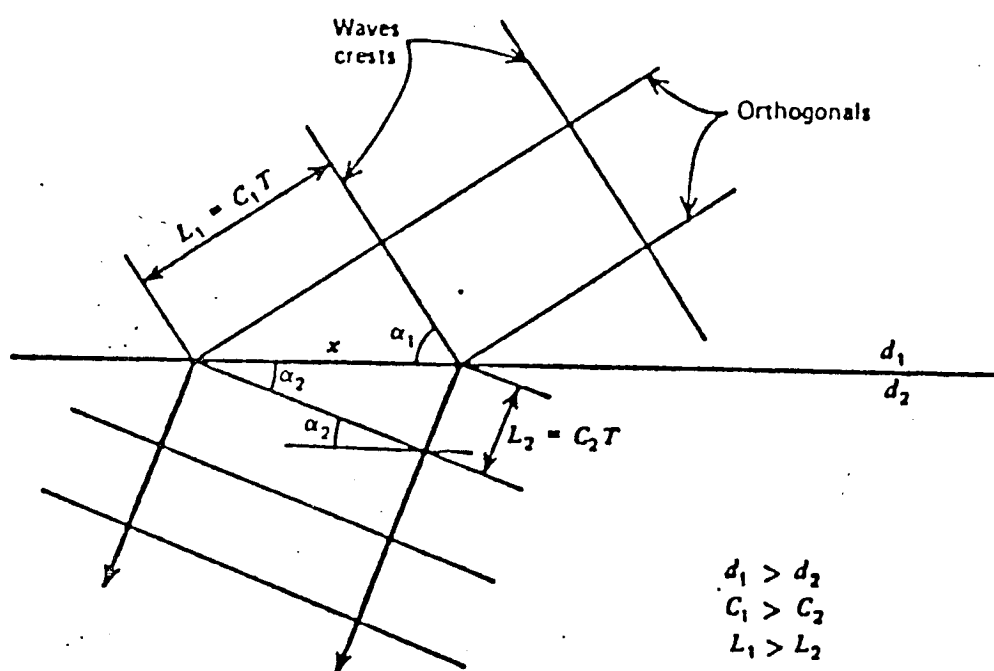


Fig 2-6 Definition sketch for Snell's Law derivation.

Wave power is wave energy per unit time. One would arrive at the following relations after integrating the expression for the average power per unit crest width over the whole wave period and water depth.

$$n = \frac{1}{2} \left[1 + \frac{2\pi d/L}{\sinh(2\pi d/L)} \right] \quad (2-8)$$

$$\bar{P} = n b \bar{E} C \quad (2-9)$$

Assuming no energy transfer along wave crests, power transfer from deep water to shallow water between wave orthogonals is constant. By equating 2-9 from one point to another point at sea, one can assess the change in wave heights

$$\frac{H_1}{H_2} = \sqrt{\left(\frac{n_1}{n_2}\right) \left(\frac{C_1}{C_2}\right)} \sqrt{\frac{b_1}{b_2}} \quad (2-10)$$

The second term on the right is known as the shoaling coefficient (K_s). **Shoaling** is the change of wave height due to the shallowing effect. It is a vertical effect on the wave energy, squeezing the energy into a higher amplitude wave. Shoaling coefficients generally are greater than unity except for some cases in transitional depth.

The refraction coefficient (K_r) is the third term on the right. It is expressed in a ratio of two orthogonal spacings. Alternatively, K_r can be expressed as:

$$K_R = \left(\frac{b_1}{b_2}\right)^{\frac{1}{2}} = \left(\frac{\cos \alpha_1}{\cos \alpha_2}\right)^{\frac{1}{2}} \quad (2-11a)$$

and K_s as:

$$K_S = \sqrt{\left(\frac{n_1}{n_2}\right) \left(\frac{C_1}{C_2}\right)} \quad (2-11b)$$

2.1.2. Wave Diffraction

When a regular train of waves is interrupted by a barrier such as a breakwater or an islet, there would be a transfer of energy along the wave crest into the lee of the structure. The region of water behind the protective structure will experience some disturbances provided by the incoming waves. Depending on the location of interest, the level of disturbance varies.

The wave height distribution in a harbour or sheltered bay protected by natural or manmade structures can be assessed to some degree by a series of charts developed by Wiegel (Ref -15). **Diffraction** coefficients K_r can be obtained from these charts and the incident wave height can then be adjusted accordingly. Table 1 is a tabulated summary of the diffraction coefficient charts. The charts are included in Appendix B.

The charts were derived under a set of assumptions:

- i) water is inviscid and incompressible.
- ii) small amplitude waves
- iii) irrotational flow
- iv) constant depth shoreward of breakwater.

2.1.2.1 Floating Breakwaters

The diffraction theory was based on waves interferred by impermeable structures. The most common type of barrier would be a rubble mound breakwater. Floating breakwaters, however, are also used to protect some harbours from wave attacks. Floating breakwaters are usually used in relatively sheltered locations where fetch distances are too short to permit wind generation of waves with significantly long periods (>6 sec). For harbours on the Pacific coast, wind generated waves predominantly have periods under 6 seconds; therefore, floating breakwaters are quite common in the region.

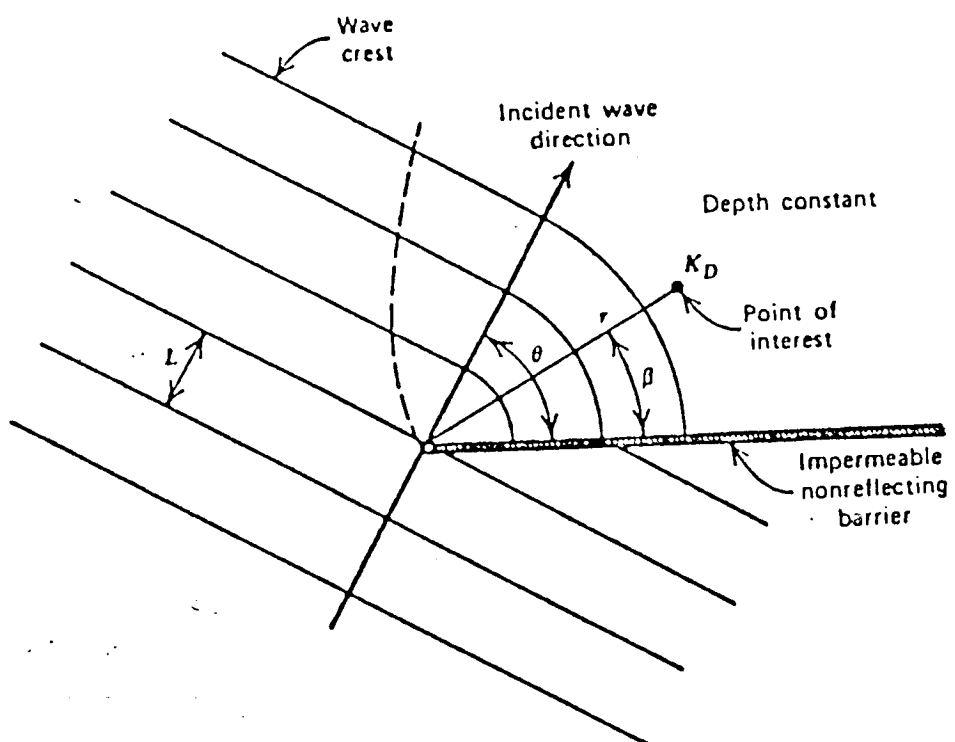


Fig 2-7 Wave diffraction behind a barrier.

Table 1 WAVE DIFFRACTION COEFFICIENTS, K_D ,
AS A FUNCTION (WIEGEL, 1962)

r/L	β (Degrees)													
	0	15	30	45	60	75	90	105	120	135	150	165	180	
$\theta = 15^\circ$														
1/2	0.49	0.79	0.83	0.90	0.97	1.01	1.03	1.02	1.01	0.99	0.99	1.00	1.00	
1	0.38	0.73	0.83	0.95	1.04	1.04	0.99	0.98	1.01	1.01	1.00	1.00	1.00	
2	0.21	0.68	0.86	1.05	1.03	0.97	1.02	0.99	1.00	1.00	1.00	1.00	1.00	
5	0.13	0.63	0.99	1.04	1.03	1.02	0.99	0.99	1.00	1.01	1.00	1.00	1.00	
10	0.35	0.58	1.10	1.05	0.98	0.99	1.01	1.00	1.00	1.00	1.00	1.00	1.00	
$\theta = 30^\circ$														
1/2	0.61	0.63	0.68	0.76	0.87	0.97	1.03	1.05	1.03	1.01	0.99	0.95	1.00	
1	0.50	0.53	0.63	0.78	0.95	1.06	1.05	0.98	0.98	1.01	1.01	0.97	1.00	
2	0.40	0.44	0.59	0.84	1.07	1.03	0.96	1.02	0.98	1.01	0.99	0.95	1.00	
5	0.27	0.32	0.55	1.00	1.04	1.04	1.02	0.99	0.99	1.00	1.01	0.97	1.00	
10	0.20	0.24	0.54	1.12	1.06	0.97	0.99	1.01	1.00	1.00	1.00	0.98	1.00	
$\theta = 45^\circ$														
1/2	0.49	0.50	0.55	0.63	0.73	0.85	0.96	1.04	1.06	1.04	1.00	0.99	1.00	
1	0.38	0.40	0.47	0.59	0.76	0.95	1.07	1.06	0.98	0.97	1.01	1.01	1.00	
2	0.29	0.31	0.39	0.56	0.83	1.08	1.04	0.96	1.03	0.98	1.01	1.00	1.00	
5	0.18	0.20	0.29	0.54	1.01	1.04	1.05	1.03	1.00	0.99	1.01	1.00	1.00	
10	0.13	0.15	0.22	0.53	1.13	1.07	0.96	0.98	1.02	0.99	1.00	1.00	1.00	
$\theta = 60^\circ$														
1/2	0.40	0.41	0.45	0.52	0.60	0.72	0.85	1.13	1.04	1.06	1.03	1.01	1.00	
1	0.31	0.32	0.36	0.44	0.57	0.75	0.96	1.08	1.06	0.98	0.98	1.01	1.00	
2	0.22	0.23	0.28	0.37	0.55	0.83	1.08	1.04	0.96	1.03	0.98	1.01	1.00	
5	0.14	0.15	0.18	0.28	0.53	1.01	1.04	1.05	1.03	0.99	0.99	1.00	1.00	
10	0.10	0.11	0.13	0.21	0.52	1.14	1.07	0.96	0.98	1.01	1.00	1.00	1.00	
$\theta = 75^\circ$														
1/2	0.34	0.35	0.38	0.42	0.50	0.59	0.71	0.85	0.97	1.04	1.05	1.02	1.00	
1	0.25	0.26	0.29	0.34	0.43	0.56	0.75	0.95	1.02	1.06	0.98	0.98	1.00	
2	0.18	0.19	0.22	0.26	0.36	0.54	0.83	1.09	1.04	0.96	1.03	0.99	1.00	
5	0.12	0.12	0.13	0.17	0.27	0.52	1.01	1.04	1.05	1.03	0.99	0.99	1.00	
10	0.08	0.08	0.10	0.13	0.20	0.52	1.14	1.07	0.96	0.98	1.01	1.00	1.00	
$\theta = 90^\circ$														
1/2	0.31	0.31	0.33	0.36	0.41	0.49	0.59	0.71	0.85	0.96	1.03	1.03	1.00	
1	0.22	0.23	0.24	0.28	0.33	0.42	0.56	0.75	0.96	1.07	1.05	0.99	1.00	
2	0.16	0.16	0.18	0.20	0.26	0.35	0.54	0.69	1.08	1.04	0.96	1.02	1.00	
5	0.10	0.10	0.11	0.13	0.16	0.27	0.53	1.01	1.04	1.05	1.02	0.99	1.00	
10	0.07	0.07	0.08	0.09	0.13	0.20	0.52	1.14	1.07	0.96	0.99	1.01	1.00	

OF INCIDENT WAVE DIRECTION θ , AND POSITION, r/L AND β

r/L	β (Degrees)													
	0	15	30	45	60	75	90	105	120	135	150	165	180	
$\theta = 105^\circ$														
1/2	0.28	0.28	0.29	0.32	0.35	0.41	0.49	0.59	0.72	0.85	0.97	1.01	1.00	
1	0.20	0.20	0.24	0.23	0.27	0.33	0.42	0.56	0.75	0.95	1.06	1.04	1.00	
2	0.14	0.14	0.13	0.17	0.20	0.25	0.35	0.54	0.83	1.08	1.03	0.97	1.00	
5	0.09	0.09	0.10	0.11	0.13	0.17	0.27	0.52	1.02	1.04	1.04	1.02	1.00	
10	0.07	0.06	0.08	0.08	0.09	0.12	0.20	0.52	1.14	1.07	0.97	0.99	1.00	
$\theta = 120^\circ$														
1/2	0.25	0.26	0.27	0.28	0.31	0.35	0.41	0.50	0.60	0.73	0.87	0.97	1.00	
1	0.18	0.19	0.19	0.21	0.23	0.27	0.33	0.43	0.57	0.76	0.95	1.04	1.00	
2	0.13	0.13	0.14	0.14	0.17	0.20	0.26	0.16	0.55	0.83	1.07	1.03	1.00	
5	0.08	0.08	0.08	0.09	0.11	0.13	0.16	0.27	0.53	1.01	1.04	1.03	1.00	
10	0.06	0.06	0.06	0.07	0.07	0.09	0.13	0.20	0.52	1.13	1.06	0.98	1.00	
$\theta = 135^\circ$														
1/2	0.24	0.24	0.25	0.26	0.28	0.32	0.36	0.42	0.52	0.63	0.76	0.90	1.00	
1	0.18	0.17	0.18	0.19	0.21	0.23	0.28	0.34	0.44	0.59	0.78	0.95	1.00	
2	0.12	0.12	0.13	0.14	0.14	0.17	0.20	0.26	0.37	0.56	0.84	1.05	1.00	
5	0.08	0.07	0.08	0.08	0.09	0.11	0.13	0.17	0.28	0.54	1.00	1.04	1.00	
10	0.05	0.06	0.06	0.06	0.07	0.08	0.09	0.13	0.21	0.53	1.12	1.05	1.00	
$\theta = 150^\circ$														
1/2	0.23	0.23	0.24	0.25	0.27	0.29	0.33	0.38	0.45	0.55	0.68	0.83	1.00	
1	0.16	0.17	0.17	0.18	0.19	0.22	0.24	0.29	0.36	0.47	0.63	0.83	1.00	
2	0.12	0.12	0.12	0.13	0.14	0.15	0.18	0.22	0.28	0.39	0.59	0.86	1.00	
5	0.07	0.07	0.08	0.08	0.08	0.10	0.11	0.13	0.18	0.29	0.55	0.99	1.00	
10	0.05	0.05	0.05	0.06	0.06	0.07	0.08	0.10	0.13	0.22	0.54	1.10	1.00	
$\theta = 165^\circ$														
1/2	0.23	0.23	0.23	0.24	0.26	0.28	0.31	0.35	0.41	0.50	0.63	0.79	1.00	
1	0.16	0.16	0.17	0.17	0.19	0.20	0.23	0.26	0.32	0.40	0.53	0.73	1.00	
2	0.11	0.11	0.12	0.12	0.13	0.14	0.16	0.19	0.23	0.31	0.44	0.68	1.00	
5	0.07	0.07	0.07	0.07	0.08	0.09	0.10	0.12	0.15	0.20	0.32	0.63	1.00	
10	0.05	0.05	0.05	0.06	0.06	0.06	0.07	0.08	0.11	0.11	0.21	0.58	1.00	
$\theta = 180^\circ$														
1/2	0.20	0.25	0.23	0.24	0.25	0.28	0.31	0.34	0.40	0.49	0.61	0.78	1.00	
1	0.10	0.17	0.16	0.18	0.18	0.23	0.22	0.25	0.31	0.38	0.50	0.70	1.00	
2	0.02	0.09	0.12	0.12	0.13	0.18	0.16	0.18	0.22	0.29	0.40	0.60	1.00	
5	0.02	0.06	0.07	0.07	0.07	0.08	0.10	0.12	0.14	0.18	0.27	0.46	1.00	
10	0.01	0.05	0.05	0.04	0.06	0.07	0.07	0.08	0.10	0.13	0.20	0.36	1.00	

The efficiency of floating breakwaters varies markedly with the length and period of incident waves. The width of floating breakwater to effectively reduce incident waves increases rapidly as incident wave period increases beyond 3 seconds. In fact, floating breakwaters are most effective against waves with period of less than 4 seconds.

The lack of sufficient details regarding the floating breakwater specifications did not permit the analyst to accurately determine the performance of each structure at the various sites. Although the waves in the analysis were predominantly short-period waves, significant amount of incident waves can be transmitted, especially waves with period near 6 sec. However, for simplicity, the floating breakwater in the diffraction analysis were all treated essentially as impermeable structures.

2.1.3 Wave Reflection

The effect of wave reflection has been ignored in our analysis. The waves are assumed to be completely absorbed at shorelines.

2.1.4 Summary of Wave Mechanics

	Range	Celerity C	Celerity Ratio n
Deep Water Waves	$0.5 < d/L$	$\frac{gT}{2\pi}$	0.5
Transitional Water Waves	$0.5 > d/L > 0.05$	$\frac{gT}{2\pi} \tanh\left(\frac{2\pi d}{L}\right)$	$\frac{1}{2} \left[1 + \frac{2\pi d/L}{\sinh(2\pi d/L)} \right]$
Shallow Water Waves	$d/L < 0.05$	$\sqrt{gd}$	1.0

By incorporating all the near-shore effects on wave heights, one would

be able to assess the wave characteristics of any point in a given harbour site.

$$H_2 = H_1 K_s K_r K_d$$

(2-12)

2.2 Wave Hindcasting

We have previously discussed surface waves from the standpoint of motions and transformations without regard to wave generation. Real waves are much less regular than those implied by theory. It is best to represent the complex real sea condition by a small number of parameters.

Wave hindcasting is the analysis and prediction of wave condition based on past meteorological conditions. There are simplified and complex hindcasting procedures. The simplified prediction systems are essentially empirical procedures whereas complex prediction methods attempt to simulate numerically the physics of wave generation, dissipation and shallow water effects. Analytical results from the complex procedures generally try to define energy levels by frequency and direction. These complex models are referred to as discrete parametric or discrete spectral models. They require fairly extensive computational resources and are relatively lengthy and expensive. For the purpose of our studies, the simplified procedure was adopted.

2.2.1 Input Parameters for **SMB** Hindcasting Model

The most common hindcasting method was developed by Sverdrup and Munk, later revised by Bretschneider (SMB). This hindcasting procedure assumes that waves are generated by a wind blowing with constant speed and direction over the generating area or fetch. Furthermore, the procedure assumes that the sea is calm when wind begins.

In order to predict wave properties from meteorological data, it is necessary to:

- i) estimate the mean surface wind speed and direction
- ii) delineate a fetch over which the wind is reasonably constant in speed and direction.
- iii) estimate wind duration over the fetch.

2.2.1.1. Meteorological Data

The wind velocity and directional information is available from existing wind records archived by Atmospheric Environment Services. Records from a large number of meteorological stations normally provide adequate coverage of all harbour sites.

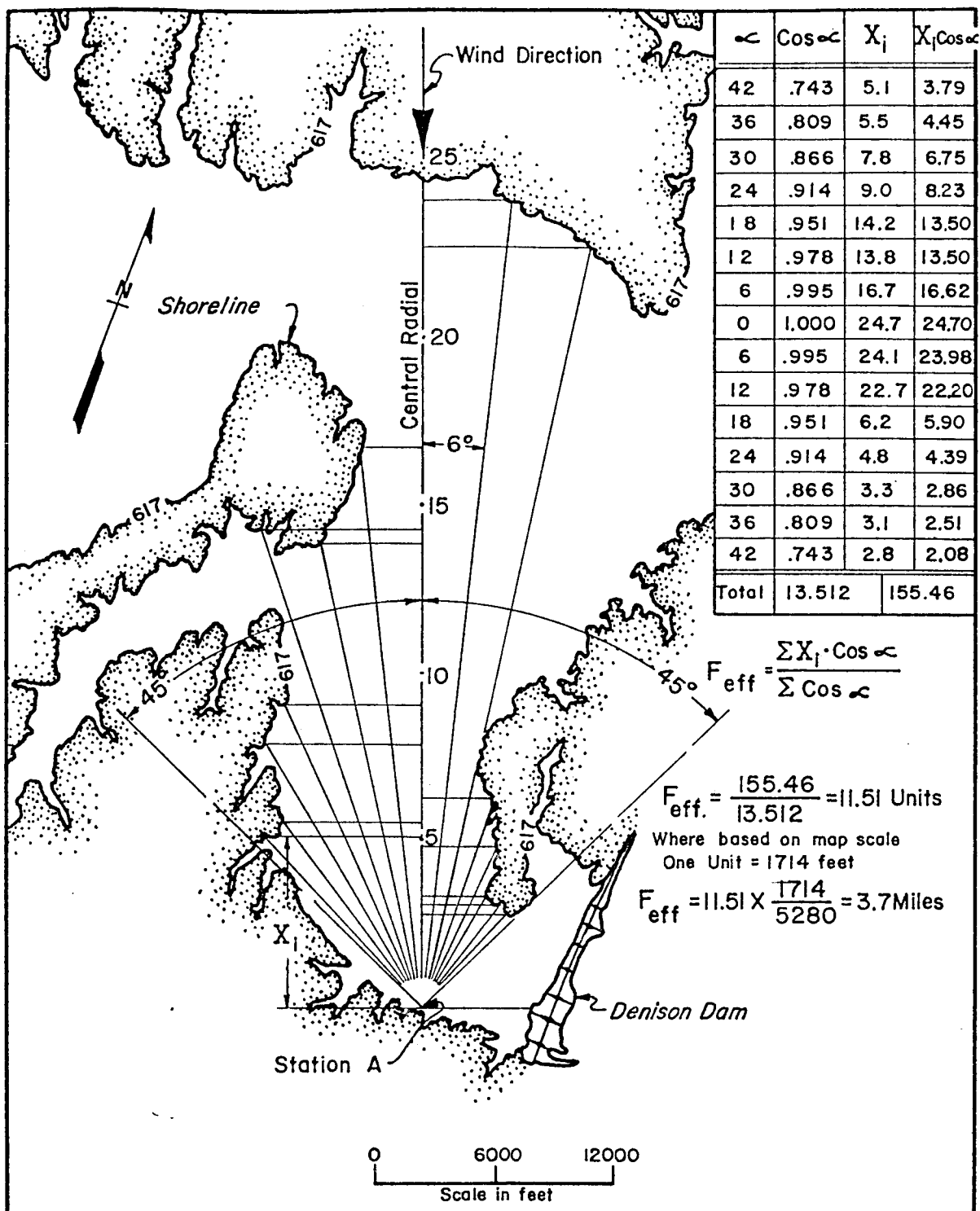
2.2.1.2 Effective Fetch

In large body of ocean water, the effect of fetch or width or limiting ocean wave growth in a generating area may usually be neglected since nearly all ocean fetches have widths as large as their lengths. However, in inland waters as in our case, fetches are limited by land forms surrounding the body of water.

An **Effective Fetch Method** (Fig. 2-8) was developed to allow the determination of fetch distances that included the effects of irregular shoreline. This graphical method is well documented in the Shore Protection Manual by the U.S. Corps of Engineers.(Ref-13).

The effective fetch method is based on a set of assumptions:

- i) over-water wind transfers energy to the water surface in the direction of the wind and within 45° on either side of the wind direction.
- ii) the wind transfers a unit amount of energy to the water along the central radial and along any other radial an amount modified by the cosine of the angle between the radial and the wind direction.
- iii) waves are completely absorbed at shorelines.



(U.S. Army, B.E.B. Tech. Memo No. 132, 1962)

Figure 2-8 Computation of Effective Fetch for Irregular Shoreline

The fetch distances determined this way are usually less than those based on maximum straight-line distances over open water. This is because the effective fetch is an average value that takes into account the irregularity of shorelines and protection provided by the neighboring landforms.

2.2.2 SMB Hindcasting Model

The **SMB Wave Hindcasting** method can be illustrated by a set of curves representing dimensional plots from several empirical equations (Fig. 2-9 and 2-10).

For hindcasting in deep water,

$$\frac{g_H}{U^2} = 0.283 \tanh \left[0.0125 \left(\frac{g_F}{U^2} \right)^{0.42} \right] \quad (2-13)$$

$$\frac{g_T}{2\pi U} = 1.20 \tanh \left[0.077 \left(\frac{g_F}{U^2} \right)^{0.25} \right] \quad (2-14)$$

$$\frac{g_t}{U} = K \exp \left\{ \left[A \left(\ln \left(\frac{g_F}{U^2} \right) \right)^2 - B \ln \left(\frac{g_F}{U^2} \right) + C \right]^{\frac{1}{2}} + D \ln \left(\frac{g_F}{U^2} \right) \right\} \quad (2-15)$$

$$K = 6.5832$$

$$A = 0.0161$$

$$B = 0.3692$$

$$c = 2.2024$$

$$D = 0.8798$$

$$g = 32.2$$

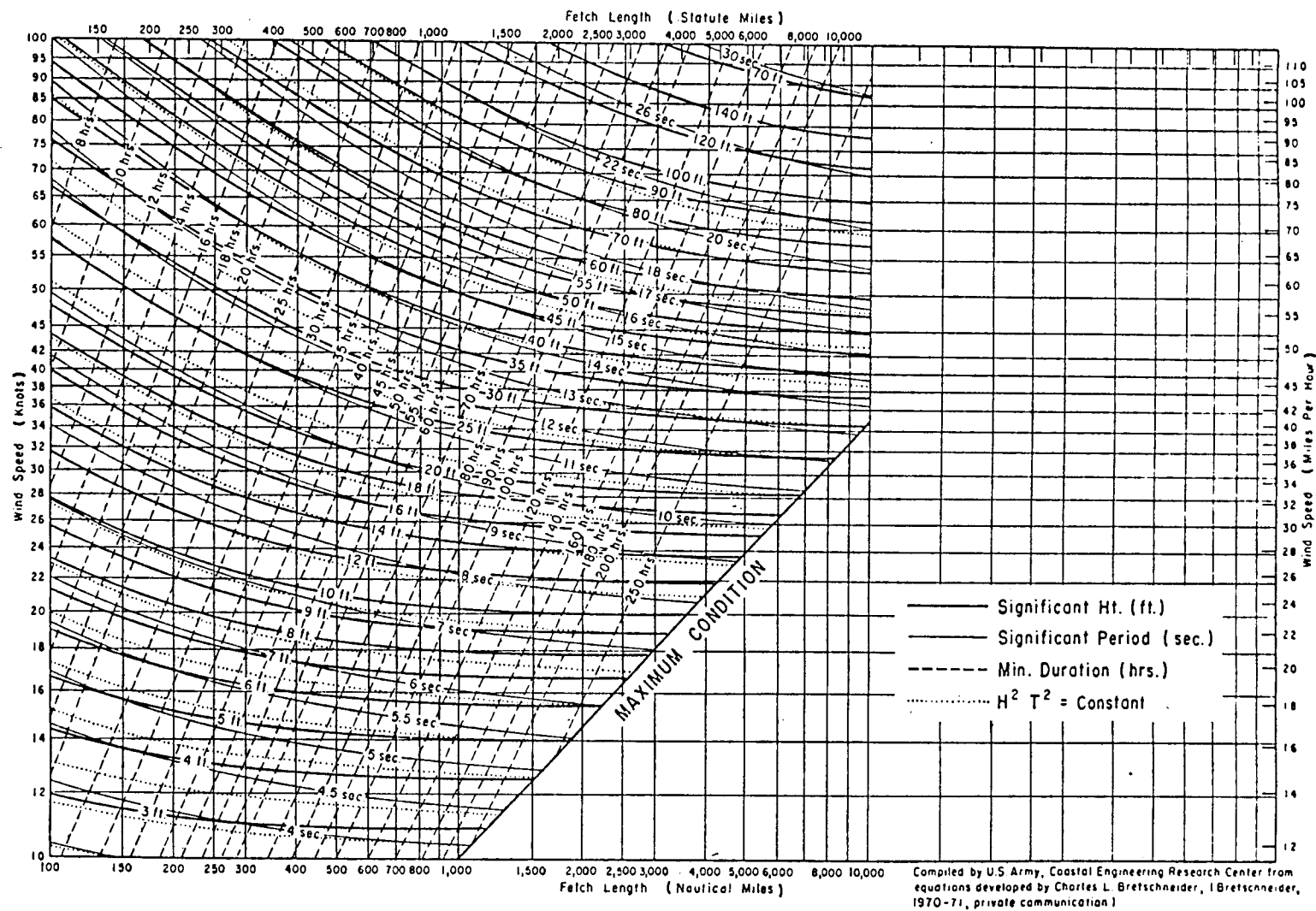


Figure 2-10 Deepwater Wave Forecasting Curves as a Function of Wind Speed, Fetch Length, and Wind Duration (for Fetches of 100 to more than 1,000 miles)

The parameters in the above equations consist of respectively the wind speed U (knots), the fetch F (nautical miles), the duration t (hrs), the significant wave height H (ft), and the significant wave period T (sec).

For a given wind speed and fetch, one may use equation 2-15 to calculate the wind duration. In order to determine if the condition is **duration limited** or **fetch limited** equation 2-13 and 2-14 can be used to verify each condition.

Waves are duration limited when they reach their maximum allowable height under the generating wind before approaching the end of the fetch length. The growth in wave height is limited only by the wind duration and not by the fetch length. From the point when the waves reach their limiting height (the wave condition known as Fully Developed Sea), the waves would begin to decay over the balance of the fetch. Fetch limited is when waves reach the end of the fetch length before being able to fully develop their heights. Here, the fetch distance determines the significant wave height and period regardless of the wind duration.

After one has determined the limiting condition, equation 2-13 and 2-14 can be used to calculate the significant wave heights and period.

For fairly well protected coastline as in the Pacific Region, the fetch limited case is the most dominant situation.

The significant wave height and period obtained from the SMB prediction system give an estimate of deep water wave conditions. For conditions close to shore, one has to carry out refraction, diffraction, and shoaling analysis to account for the appropriate adjustment. From the deep water hindcasting results, one can then derive the various input parameters required for these analyses.

3. Wave Climate Analysis

SCH had chosen to adopt a simplified hindcasting and analytical modelling system that would yield quick and reasonable estimates of the wave condition actually experienced at each of the 220 harbour sites.

3.1 Determination of SMB Parameters

3.1.1 Over-water Wind Field

The over-water wind field may be determined by wind data collected from lightstations, islands, and piers. Wind records indicating wind speed, direction, and duration, recorded by a large number of meteorological stations, are archived by the AES. When choosing records for the study of a particular harbour, one has to consider the station's proximity to the harbour as well as the resemblance of the station's neighbouring geography to that of the site. In addition to accounting for difference in location, one must also consider elevation difference between the station's anemometer and the harbour site. The elevation difference may affect the actual wind speed at the harbour due to varying boundary layer wind velocity profile with height. Other factors that might affect wind velocities at the site include air-sea temperature differences and major topographic differences. All proposed modifications on the wind data would eventually take the form of a single correction factor. The adjustment, though, requires professional judgement and experience, and can by no means be exact. Furthermore, the ranges of error are difficult to determine. In light of the uncertainties in modifying wind data, the adjustments were left out of our analysis.

3.1.2 Effective Fetch

For a given harbour, the facilities are vulnerable to wave attack in a number of directions (8-point compass). In order to determine the total wave agitation at a harbour, effective fetch distances in each of the

exposed directions must be measured.

The effective fetch method used was, however slightly modified from the conventional method (Fig. 3-1). The analyst designed this modification to account for waves arriving from far fetches, refracting around protective landforms, and somehow managing to reach the harbour. These faraway fetches were not considered by the conventional method because the radials were stopped as soon as they intercepted a shoreline. Often, these interceptions may only be a portion of a small land mass that in reality will not provide adequate protection. Therefore, in cases where radials were intercepted by small portions of land, the radials were extended beyond the initial contact point to where it intercepted a larger land mass. The logic behind this modification lies in the assumption that waves refract or bend more easily around small landmasses than around larger ones.

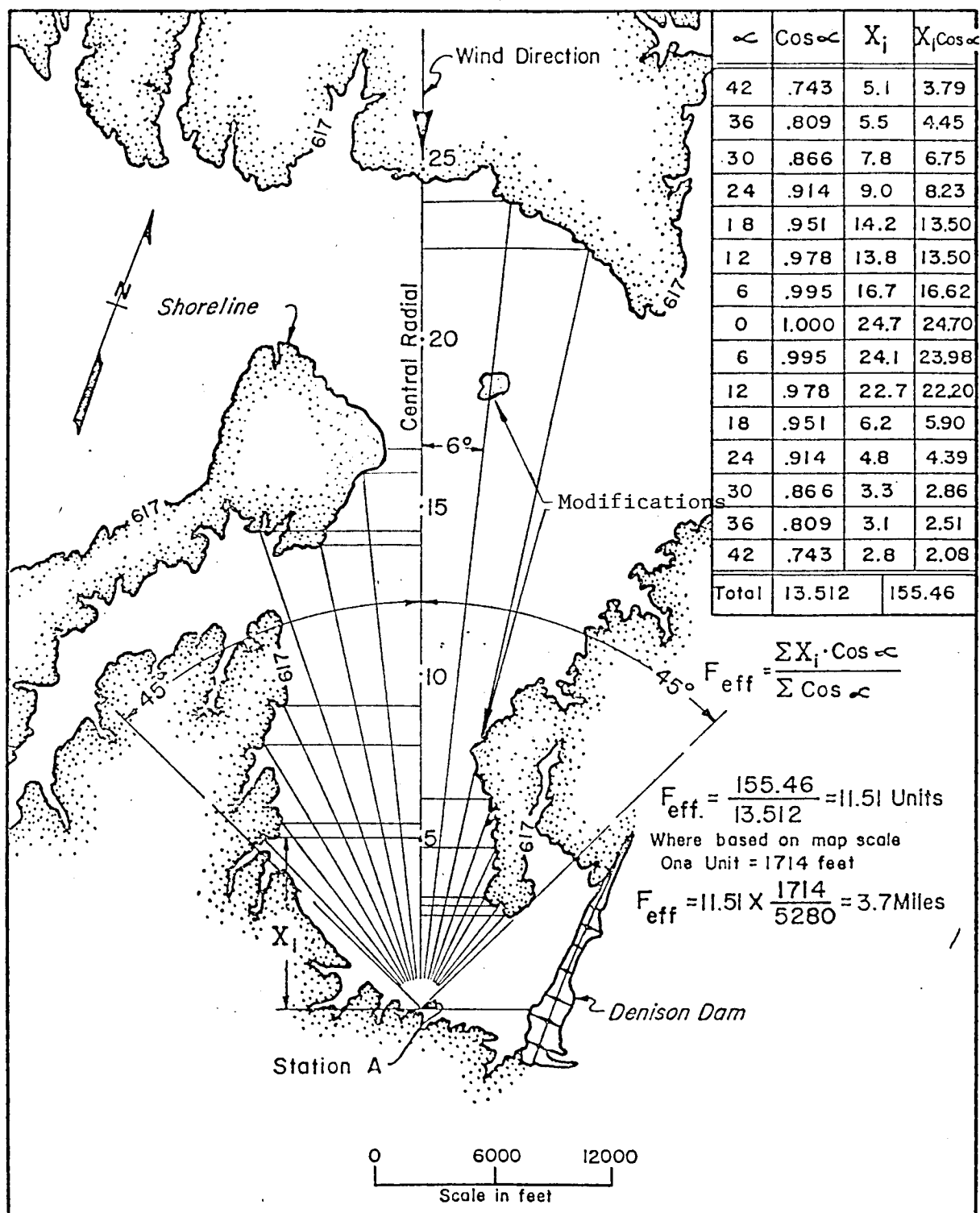
3.2 Determination of Deep Water Wave Characteristics

The analyst entered each fetch distance determined in section 3.1 with a set of wind velocity into the SMB deep water Wave Hindcasting model to determine a range of deep-water significant wave heights and periods. Wind velocity ranged from 20 km/hr to 60 km/hr. This range of wind velocity proved to be most effective for analysis purposes on the Pacific coast.

3.3 Wave Transformation in Transitional Water

3.3.1 Refraction

The harbour basins in the Pacific mostly have transitional water depths. Therefore, appropriate equations must be used to calculate transitional wave characteristics. Incident deep water waves will undergo refraction as they approach the harbour. For simplicity, the analyst made



(U.S. Army, B.E.B. Tech. Memo No. 132, 1962)

Figure 3-1 Computation of Effective Fetch for Irregular Shoreline

the assumption that the harbour basin had a uniform depth with breakwaters and legal lots forming the basin boundary. Furthermore, the analyst assumed that incident deep-water waves would undergo a single step change in depth when arriving at the harbour. The analyst considered these assumptions to be reasonable for short period waves as only small errors would be introduced to the angle of refraction.

Short period waves (≤ 6 Sec) refract very little. The coefficient of refraction varies with the ratio of deep-sea and near-shore wave celerity. Since wave celerity is determined by wave period, the amount of refraction would be very much dependant on the wave period.

From the significant wave periods determined from sec. 3.2, the deep water wave celerities can be calculated from equation 2-4. In addition, α_1 can be determined from the angle that the in-coming wave crest make with the boundary of the basin. The wave celerity in the harbour can be determined by applying equation 2-2 in parallel with equation 2-16.

$$\left(\frac{2\pi d}{L}\right) \tanh\left(\frac{2\pi d}{L}\right) = 4\pi^2 \frac{d}{gT^2} \quad 2-16$$

Then, by applying Snell's law (equation 2-6), the analyst could calculate α_2 and hence the refraction coefficient by equation 2-11a.

3.3.2 Shoaling

The shoaling coefficient can be calculated by equation 2-11b.

3.3.3 Diffraction

Incident waves approaching a harbour would be diffracted by a breakwater or any type of protective barriers. The analyst based his diffraction analysis on only one point in the harbour, a location where he

considered most vulnerable to wave attack. The wave agitation at this location was used to represent the wave agitation for all other facilities at the site, the analyst considered this a conservative approximation.

The analyst performed his wave agitation study on a year round basis. Although the harbour activity drops drastically during the winter months, (typically about 1/4 of peak level), activity level during the stormy season is usually still quite significant in the Pacific Region.

Fig 3-2 defines the parameter θ, ϕ , and r . The angle θ should be the incident wave angle of the orthogonal after undergoing refraction. This angle, however, was often different only by very little from the incident angle due to little refraction. The analyst's assumption that the harbour basin had constant depth greatly simplified computation. In the actual case, the waves would continue to refract while diffracting simultaneously, creating a highly complicated analysis.

3.4 Determination of Wave Agitation

3.4.1 Agitation by Wind Generated Waves

In section 3.2, a set of wind speed ranging from 20 km/hr to 60 km/hr were used to hindcast wave heights and periods in each fetch direction. After the deep water wave conditions had been adjusted in refraction, shoaling and diffraction, the resultant transitional water wave heights at the point of interest were compared to design wave height 0.25 m (0.82 ft) specified by the **Guidelines of Accommodation** as the maximum allowable significant wave height for berthing areas (Ref - 9). The critical wind velocity that would generate the design wave height at the point in basin was then identified. The analyst would repeat the same process for each fetch direction. This set of critical wind speeds was then used to define the input criteria (Table 2) for meteorological data processing program to determine the total number of hours that these critical velocities were

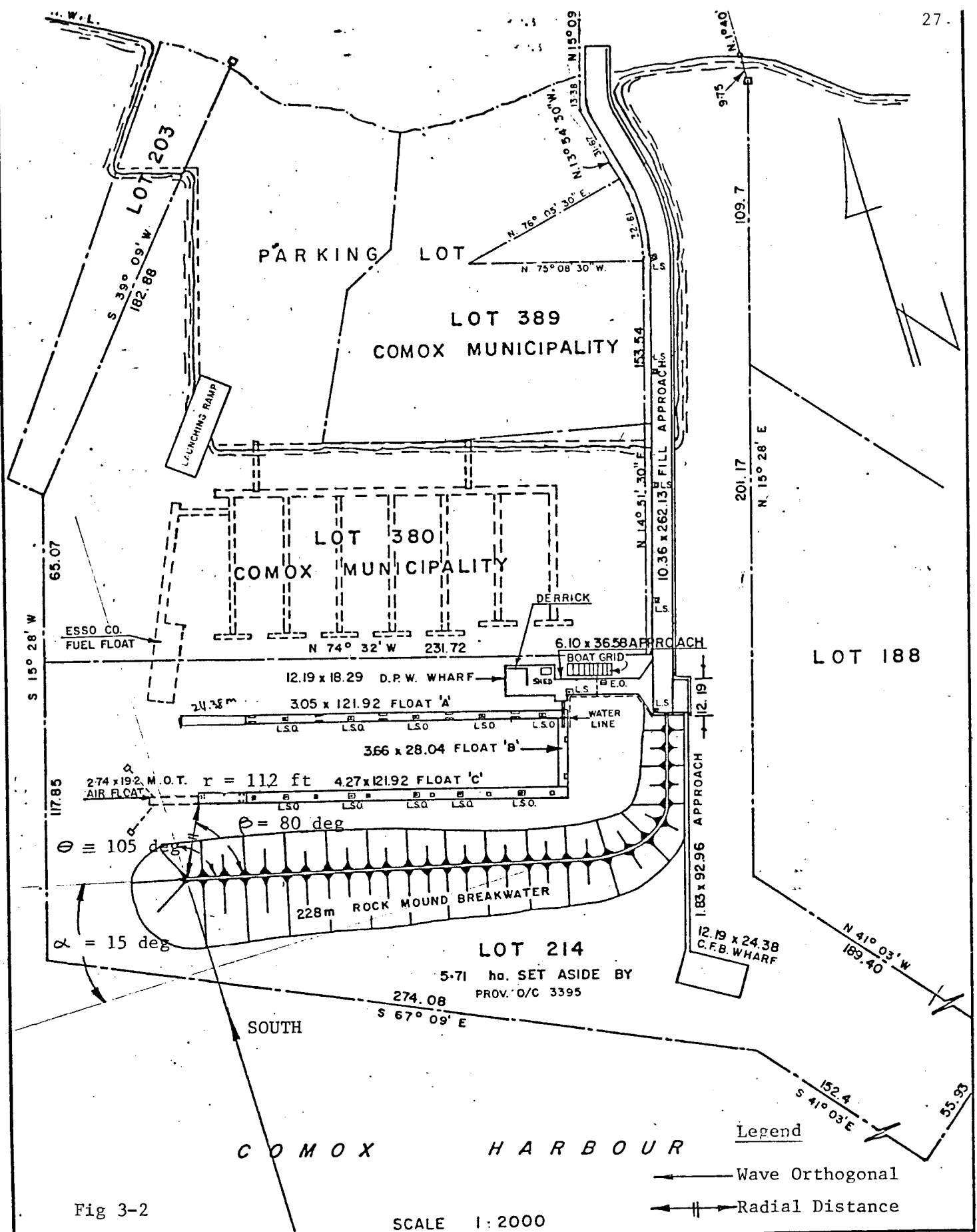


Fig 3-2

SCALE 1 : 2000

drawing title

COMOX B.C.
BOAT HARBOUR

drawn by K.R. date

revised	D.F.	FEB 1980	date
		DEC. 1978	

manager marine services date

Table 2

Atmospheric Environment Service Meteorological Data Processing Program

- Duration Analysis

RUN DATE: 17/07/85 PROGRAM: GKPIII

DEFINITION OF CONDITIONS

PROJECT: 01104 PAGE 1

WIND DIRECTION AND SPEED

CONDITION 01 = WIND DIRECTION N AND SPEED GREATER THAN 20 KM/HR
 (EL.070 FROM 0021 TO 0049)
 AND (EL.100 FROM 0030 TO 0036)
 WHERE: ELEMENT 070 = WIND SPEED (KM/HR) ; ELEMENT 100 = WIND DIRECTION (* 10)
 EXTREMES ELEMENT 070 = WIND SPEED (KM/HR) ALLOWING FOR DROPOUTS OF UP TO 3 INTERVALS

CONDITION 02 = WIND DIRECTION NE AND SPEED GREATER THAN 20 KM/HR
 (EL.070 FROM 0021 TO 0049)
 AND (EL.100 FROM 0030 TO 0036)
 WHERE: ELEMENT 070 = WIND SPEED (KM/HR) ; ELEMENT 100 = WIND DIRECTION (* 10)
 EXTREMES ELEMENT 070 = WIND SPEED (KM/HR) ALLOWING FOR DROPOUTS OF UP TO 3 INTERVALS

CONDITION 03 = WIND DIRECTION E AND SPEED GREATER THAN 20 KM/HR
 (EL.070 FROM 0021 TO 0049)
 AND (EL.100 FROM 0030 TO 0036)
 WHERE: ELEMENT 070 = WIND SPEED (KM/HR) ; ELEMENT 100 = WIND DIRECTION (* 10)
 EXTREMES ELEMENT 070 = WIND SPEED (KM/HR) ALLOWING FOR DROPOUTS OF UP TO 3 INTERVALS

CONDITION 04 = WIND DIRECTION SE AND SPEED GREATER THAN 20 KM/HR
 (EL.070 FROM 0021 TO 0049)
 AND (EL.100 FROM 0030 TO 0036)
 WHERE: ELEMENT 070 = WIND SPEED (KM/HR) ; ELEMENT 100 = WIND DIRECTION (* 10)
 EXTREMES ELEMENT 070 = WIND SPEED (KM/HR) ALLOWING FOR DROPOUTS OF UP TO 3 INTERVALS

CONDITION 05 = WIND DIRECTION S AND SPEED GREATER THAN 20 KM/HR
 (EL.070 FROM 0021 TO 0049)
 AND (EL.100 FROM 0030 TO 0036)
 WHERE: ELEMENT 070 = WIND SPEED (KM/HR) ; ELEMENT 100 = WIND DIRECTION (* 10)
 EXTREMES ELEMENT 070 = WIND SPEED (KM/HR) ALLOWING FOR DROPOUTS OF UP TO 3 INTERVALS

CONDITION 06 = WIND DIRECTION SW AND SPEED GREATER THAN 20 KM/HR
 (EL.070 FROM 0021 TO 0049)
 AND (EL.100 FROM 0030 TO 0036)
 WHERE: ELEMENT 070 = WIND SPEED (KM/HR) ; ELEMENT 100 = WIND DIRECTION (* 10)
 EXTREMES ELEMENT 070 = WIND SPEED (KM/HR) ALLOWING FOR DROPOUTS OF UP TO 3 INTERVALS

CONDITION 07 = WIND DIRECTION W AND SPEED GREATER THAN 20 KM/HR
 (EL.070 FROM 0021 TO 0049)
 AND (EL.100 FROM 0030 TO 0036)
 WHERE: ELEMENT 070 = WIND SPEED (KM/HR) ; ELEMENT 100 = WIND DIRECTION (* 10)
 EXTREMES ELEMENT 070 = WIND SPEED (KM/HR) ALLOWING FOR DROPOUTS OF UP TO 3 INTERVALS

CONDITION 08 = WIND DIRECTION NW AND SPEED GREATER THAN 20 KM/HR
 (EL.070 FROM 0021 TO 0049)
 AND (EL.100 FROM 0030 TO 0036)
 WHERE: ELEMENT 070 = WIND SPEED (KM/HR) ; ELEMENT 100 = WIND DIRECTION (* 10)
 EXTREMES ELEMENT 070 = WIND SPEED (KM/HR) ALLOWING FOR DROPOUTS OF UP TO 3 INTERVALS

Table 3 Atmospheric Environment Service Meteorological Data Processing Program

- Duration Analysis

RUN DATE: 17/07/85 PROGRAM: GRP111 VALID POPULATION COUNTS BY STATION AND MONTH (IN HOURS) PROJECT: 01164 PAGE 2

STATION: 1066481 PRINCE RUPERT A

01/1985-12/1984

WIND DIRECTION AND SPEED

CONDITION	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
01	3,720	3,408	3,720	3,600	3,719	3,599	3,720	3,720	3,600	3,720	3,600	3,696
02	3,720	3,408	3,720	3,600	3,719	3,599	3,720	3,720	3,600	3,720	3,600	3,696
03	3,720	3,408	3,720	3,600	3,719	3,599	3,720	3,720	3,600	3,720	3,600	3,696
04	3,720	3,408	3,720	3,600	3,719	3,599	3,720	3,720	3,600	3,720	3,600	3,696
05	3,720	3,408	3,720	3,600	3,719	3,599	3,720	3,720	3,600	3,720	3,600	3,696
06	3,720	3,408	3,720	3,600	3,719	3,599	3,720	3,720	3,600	3,720	3,600	3,696
07	3,720	3,408	3,720	3,600	3,719	3,599	3,720	3,720	3,600	3,720	3,600	3,696
08	3,720	3,408	3,720	3,600	3,719	3,599	3,720	3,720	3,600	3,720	3,600	3,696

RUN DATE: 17/07/85 PROGRAM: GRP111

CONDITION TOTALS BY STATION AND MONTH IN (HOURS)

PROJECT: 01164 PAGE 6

STATION: 1066481 PRINCE RUPERT A

01/1985-12/1984

WIND DIRECTION AND SPEED

CONDITION	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
01	4	0	0	4	2	1	3	2	1	0	0	0
02	11	3	2	0	2	2	0	1	1	1	3	2
03	134	117	96	97	22	7	6	4	18	91	111	75
04	670	662	650	662	400	170	189	268	357	730	690	473
05	157	81	59	99	111	41	29	30	46	79	78	94
06	62	19	18	30	11	7	4	3	14	31	14	53
07	46	19	36	68	98	107	34	41	12	26	13	41
08	24	13	20	27	36	11	2	13	29	10	2	14

exceeded in an actual 5 year wind record (Table 3). The total hours of exceedence would then yield the wave agitation for a particular harbour site.

Fig. 3-3 is a flow chart that illustrates the functional steps taken by the analyst in calculating the level of wave agitation.

3.4.2 Agitation by Vessels Generated Waves

Waves generated by ships can also produce wave agitation problems at adjacent harbours and marinas. The wave heights generated depends on vessel size, hull shape and vessel speed. The best estimate of agitation by passing vessels is from site data. The duration of wave agitation by vessel traffic is usually small comparing to that produced by wind. Therefore, the effect by the vessel traffic has been considered to be negligible in the analysis. In cases where problems are significant, actual recording instruments are advised to be installed.

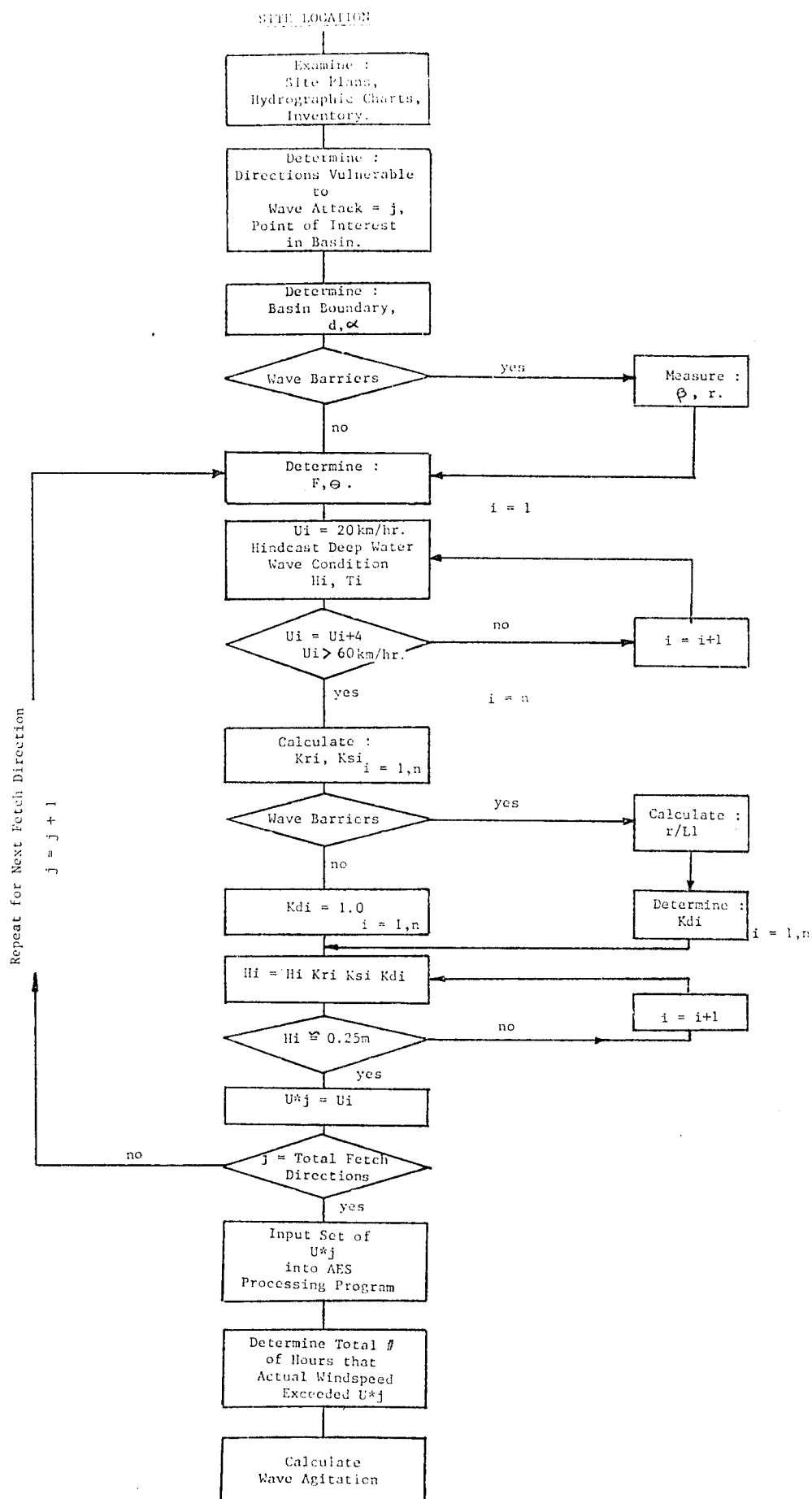


Fig 3-3

Functional Flow Diagram for
Wave Climate Analysis

4. Extensive Analysis in Wave Hindcasting and Transformation

The analyst had chosen an analytical procedure to optimize both economy and efficiency. There is an alternate way of analyzing wave climate, a procedure which is more expensive, lengthier, but more accurate.

In the procedure used in this report, the analyst had to hindcast waves in each fetch direction from a set of simulated wind speed ranging from 20 to 60 km/hr. In the alternate analysis, fetch distances can be fed directly into a hindcasting computer program at AES that would convert a 5 year wind record into a corresponding wave record. The wave record was then used to determine wave agitation. It should be noted that the local topography and configuration of each individual harbour must first be digitized to facilitate a detailed refraction and diffraction analysis included in the AES hindcasting program. The program would make adjustments on deep water wave heights as the bottom depth decreases in gradual steps.

This would give a more accurate assessment of refraction and diffraction effects as compared to a single step depth change assumed by the analyst. In planning new facilities, different harbour configurations could be tested to study the effects of wave attacks.

Although this alternate analytical procedure for wave climate is more expensive and time-consuming, it would yield quite accurate results. Such precision is often needed in planning new facilities or rehabilitating existing conditions. However, an analysis that requires extensive analysis, lengthy data preparation, and great computational efforts are not justified for the purpose of this study.

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APPENDIX A

Spreadsheet Program for Wave Climate Analysis

Spreadsheet Analysis

All the computations involved in the wave climate studies were performed on Lotus 123, an electronic spreadsheet on an IBM Personal Computer. The analyst programmed the SMB Deep Water Hindcasting System as well as the procedures for the Refraction and Shoaling Analysis onto a single worksheet.

A blank worksheet is illustrated in Fig. A-1 and A-2. The necessary input information is entered into the framed area in Fig. A-1 to initiate the analysis. The worksheet would begin computations until it reaches a pre-programmed stage when it will pause for intermediate input parameters. In particular, the program would stop as soon as it completes the d/gT^2 column. The analyst must then enter the corresponding values of L/d into the worksheet (as shown by framed area in Fig. A-2) to restart the computations. A table containing values of d/gT^2 and L/d is included in Appendix C.

Due to the complexity of the equations governing the diffraction analysis, the worksheet was programmed only to calculate the values of the parameters necessary to determine the diffraction coefficients. Table 1 can then be used to obtain the k_d manually.

Sample of a complete worksheet run is shown in Fig. A-3 and A-4. The worksheet calculates wave heights after refraction and shoaling. The coefficients of diffraction were obtained manually by values of incident angle, radial angle, and r/L ; the wave heights are then adjusted by diffraction.

A manual for using the Spreadsheet Analysis program was not completed at the time this report was compiled. However, the manual will certainly be available at a later date. At the time being, the analyst will be pleased to respond to any requests or enquiries that the reader may have.

WAVE CLIMATE ANALYSIS

Location
Lcode

:
:

Initial Input Parameters

DEEP WATER WAVE Hindcasting

Input Parameters

- i) Fetch
- ii) Wind Direction
- iii) Incident Angle
- iv) Wind Speed

:
:
:
:

ft.
deg.
ft/sec

- v) Shallow Water
Basin Depth
- vi) Radial Distance
- vii) Radial Angle

ft.
ft.
deg.

SMB Parameters

- i) E
- ii) a
- iii) B

:
:
:

6.9892
0.0151
0.2692

- iv) C
- v) D
- vi) g

2.2024
0.8798
32.15 ft/sec2

Hindcasting Results

i) Duration

- q1/2*U
- E
- D
- S
- R
- T

:
:
:
:
:
:

ERR
ERR
2.20
ERR
ERR
ERR

td

:

ERR sec.

ii) Wave Height

- V
- tanh V
- H

:
:
:

ERR
ERR
ERR (t.

T

:

ERR sec.

W

tanh W

ERR

ERR

U	H ₀	I ₀	U ₀	d1/g1+T	d1/L1	L1	U1	Fr 4PId1/L1	Ks	r/L1	H1
20.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
21.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
22.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
23.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
24.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
25.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
26.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
27.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
28.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
29.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
30.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
31.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
32.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
33.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
34.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
35.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR
36.0	0.00	0.00	0.00	ERR		ERR	ERR	ERR	ERR	ERR	ERR

Intermediate Input Parameters

WAVE CLIMATE ANALYSIS

Location : Lund
 Mode : 6087

DEEP WATER WAVE HINDCASTING

Input Parameters

i) Fetch : 36960.0 ft. v) Shallow Water
 ii) Wind Direction : W Basin Depth 20.00 ft.
 iii) Incident Angle : 22.00 deg. vi) Radial Distance 120.00 ft.
 iv) Wind Speed : 20.00 ft/sec vii) Radial Angle 80.00 deg.

SWH Parameters

i) K : 6.5882 iv) C : 2.2024
 ii) A : 0.0151 v) D : 0.8798
 iii) B : 0.3692 vi) a : 32.20 ft/sec2

Hindcasting Results

i) Duration

qE/U*U : 2975.28
 P : 7.04
 Q : 2.20
 S : 1.03
 R : 2.95
 T : 0.53

td : 11.51 sec.

ii) Wave Height

V : 0.38 W : 0.57
 tanh V : 0.34 tanh W : 0.51
 H : 1.21 ft.

 I : 2.41 sec.

Sample Run

Figure A-3

U	H0	h0	Co	d1/g1*U	d1/L1	L1	U1	Kr 4P/d1/L1	Es	r/L1	H1
20.0	1.21	2.41	12.35	0.1070	0.67	29.85	12.39	1.00	8.419	0.996	1.208
24.0	1.31	2.68	13.74	0.0954	0.60	33.33	12.43	0.99	7.540	1.047	1.574
28.0	1.82	2.93	15.01	0.0724	0.54	37.04	12.64	0.99	6.786	1.081	1.949
32.0	2.14	3.18	16.19	0.0623	0.50	40.00	12.86	0.98	6.283	1.118	2.354
36.0	2.46	3.37	17.29	0.0546	0.46	43.48	12.89	0.98	5.781	1.138	2.751
40.0	2.79	3.58	18.32	0.0486	0.42	47.62	13.32	0.98	5.278	1.143	3.126
44.0	3.12	3.77	19.31	0.0438	0.40	50.00	13.27	0.98	5.027	1.168	3.570
48.0	3.46	3.95	20.24	0.0398	0.37	54.00	13.88	0.98	4.650	1.166	3.943
52.0	3.80	4.12	21.14	0.0365	0.35	57.14	13.85	0.98	4.398	1.173	4.357
56.0	4.14	4.29	22.00	0.0337	0.33	60.61	14.12	0.98	4.147	1.174	4.751

Kd	H1
.526	.6359
.529	.8331 *
.532	1.0363
.533	1.2555
.535	1.4716
.537	1.6772
.537	1.9183
.539	2.1234
.539	2.3499
.520	2.4705

U* = 24.0 ft/s

= 26.2 km/hr

Sample Run

Figure A-4

APPENDIX B

Diffraction Charts

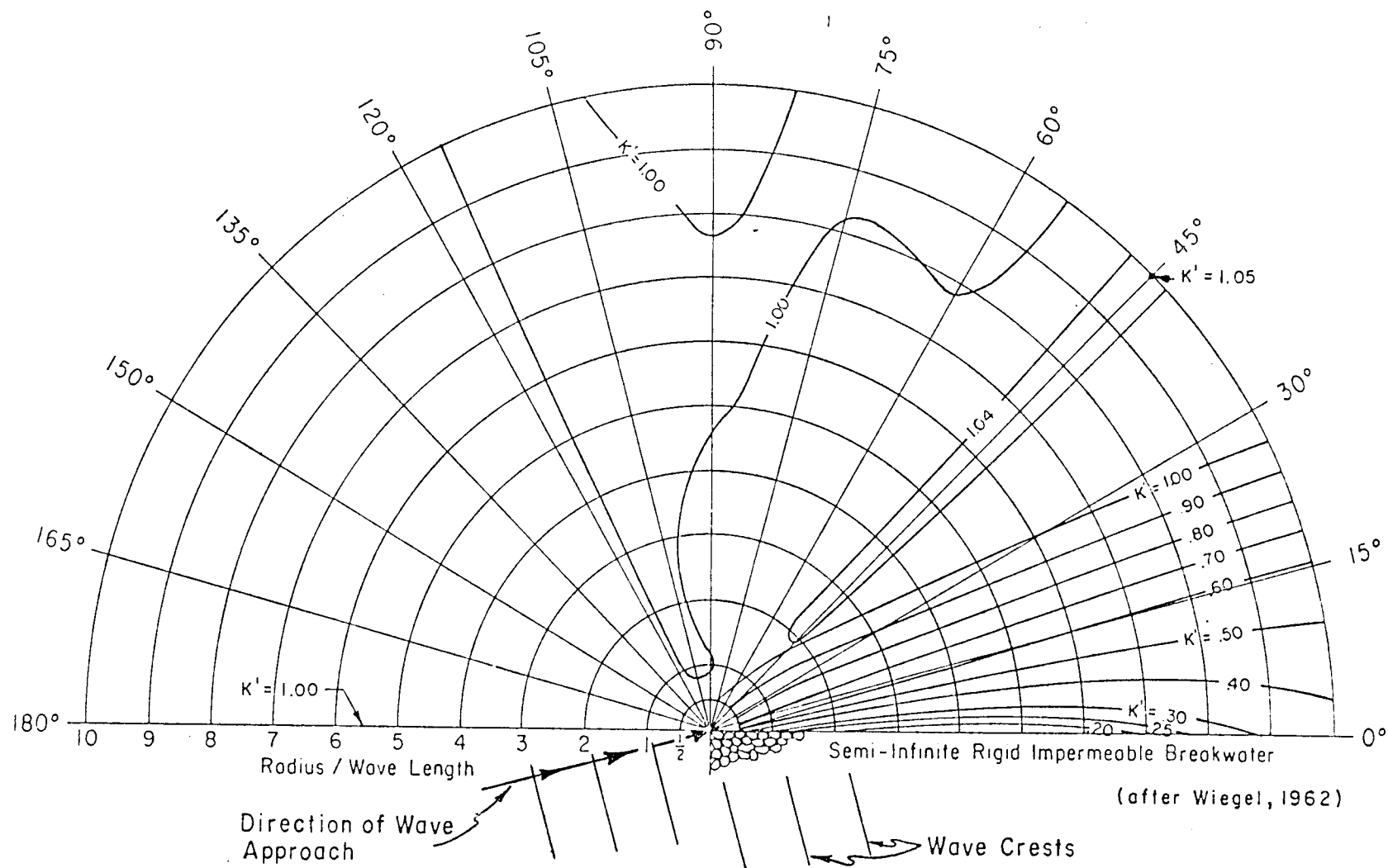


Figure B-1 Wave Diffraction Diagram - 15° Wave Angle

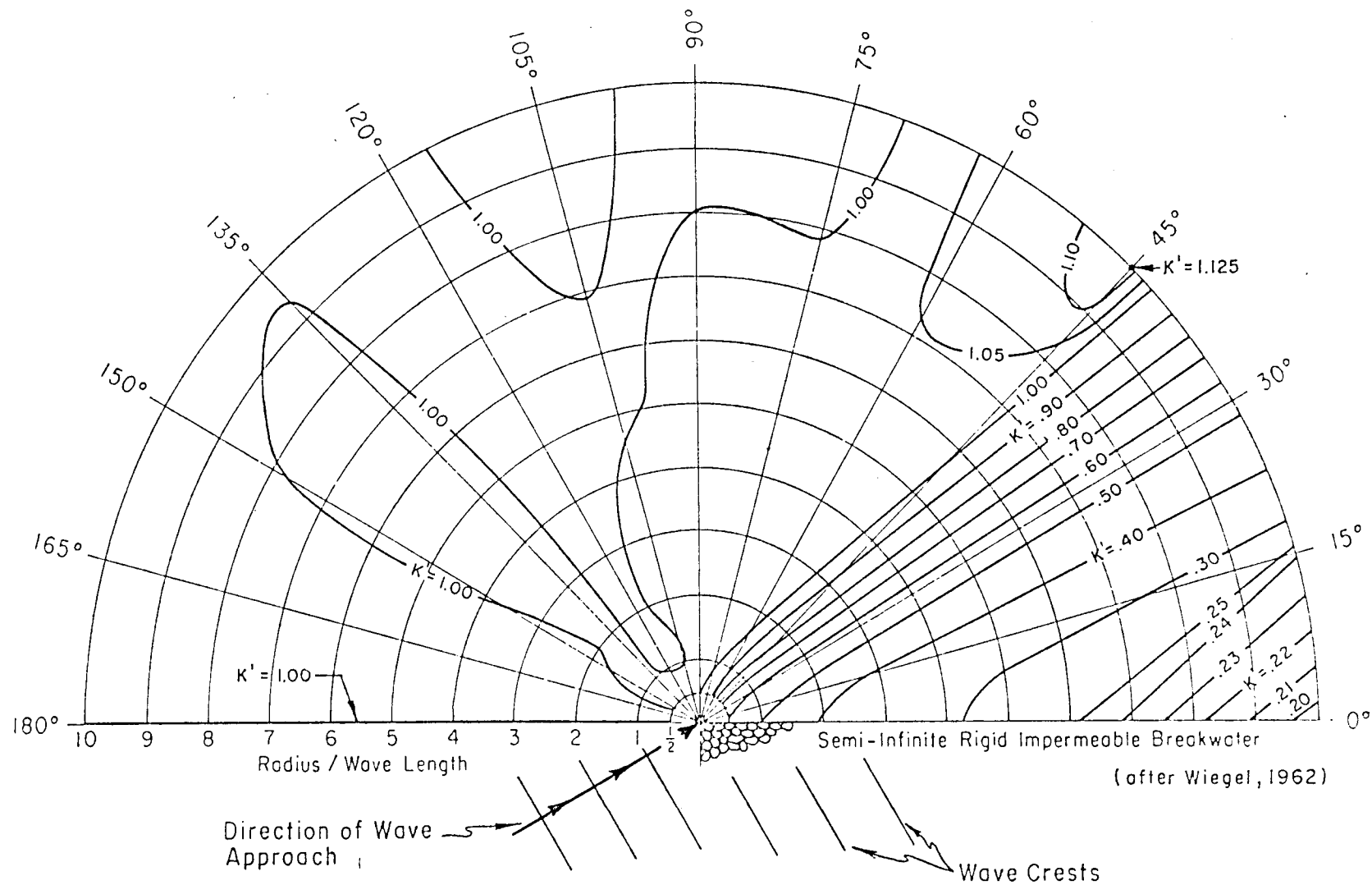


Figure B-2 Wave Diffraction Diagram - 30° Wave Angle

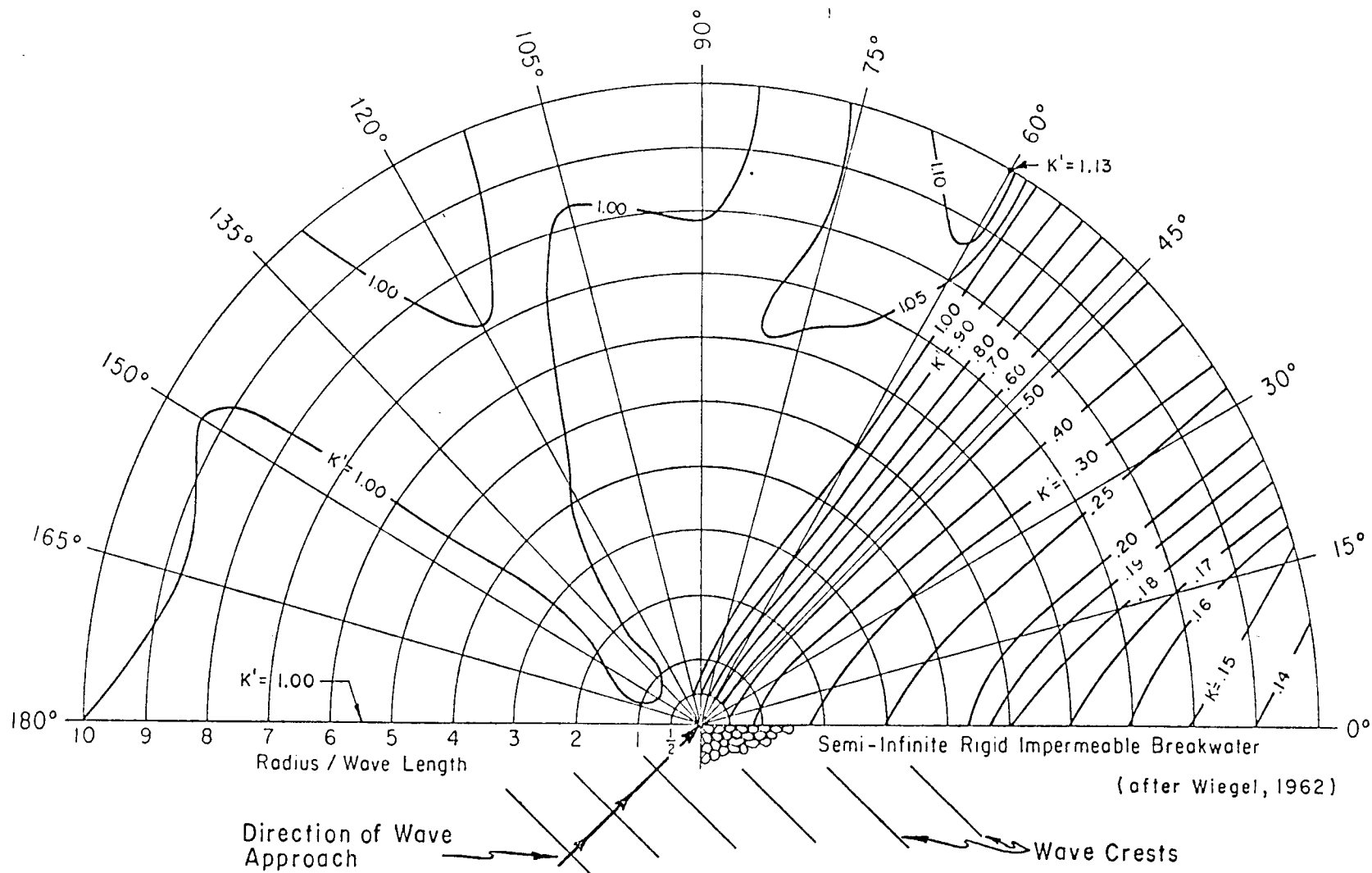


Figure B-3 Wave Diffraction Diagram - 45° Wave Angle

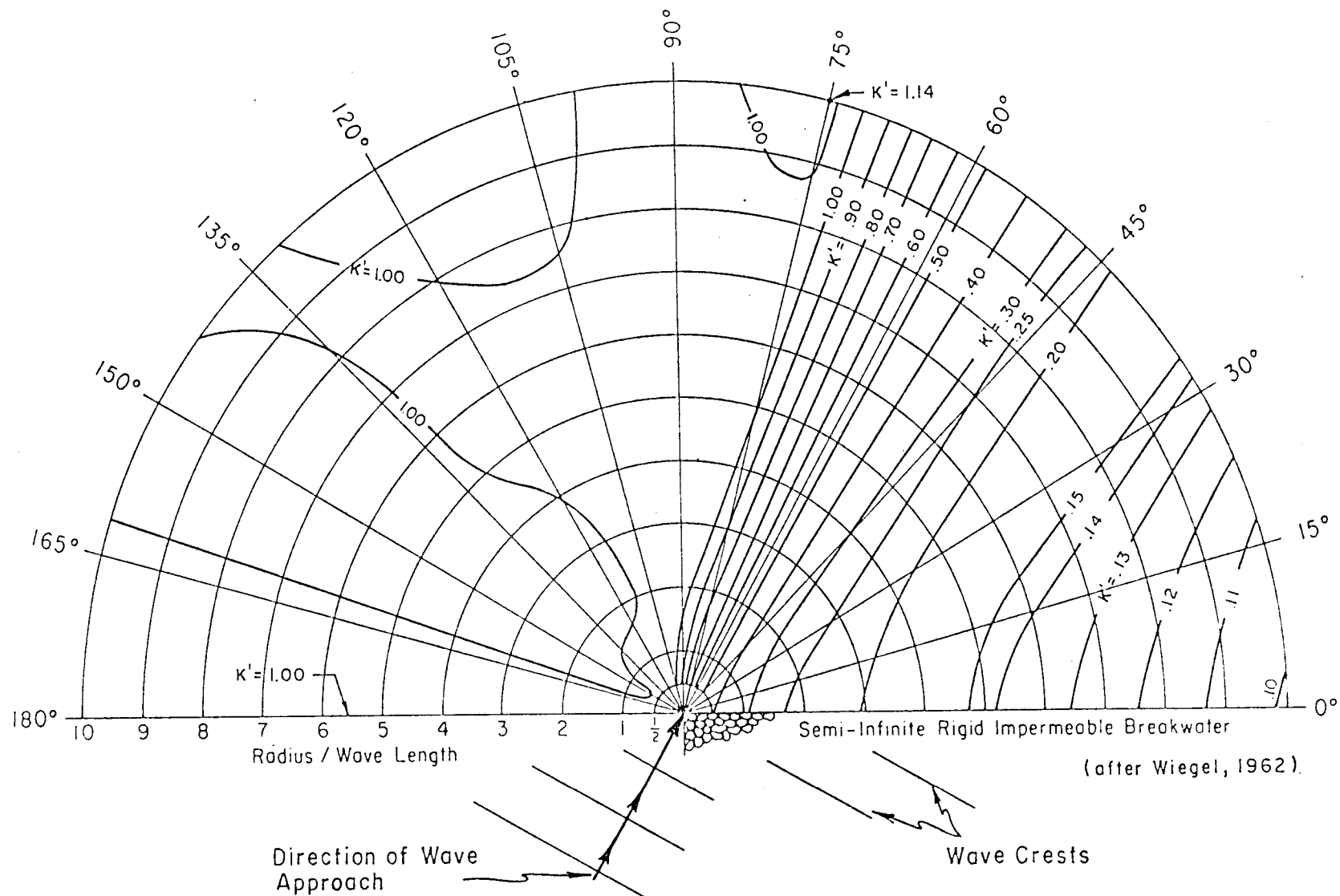


Figure B-4 Wave Diffraction Diagram - 60° Wave Angle

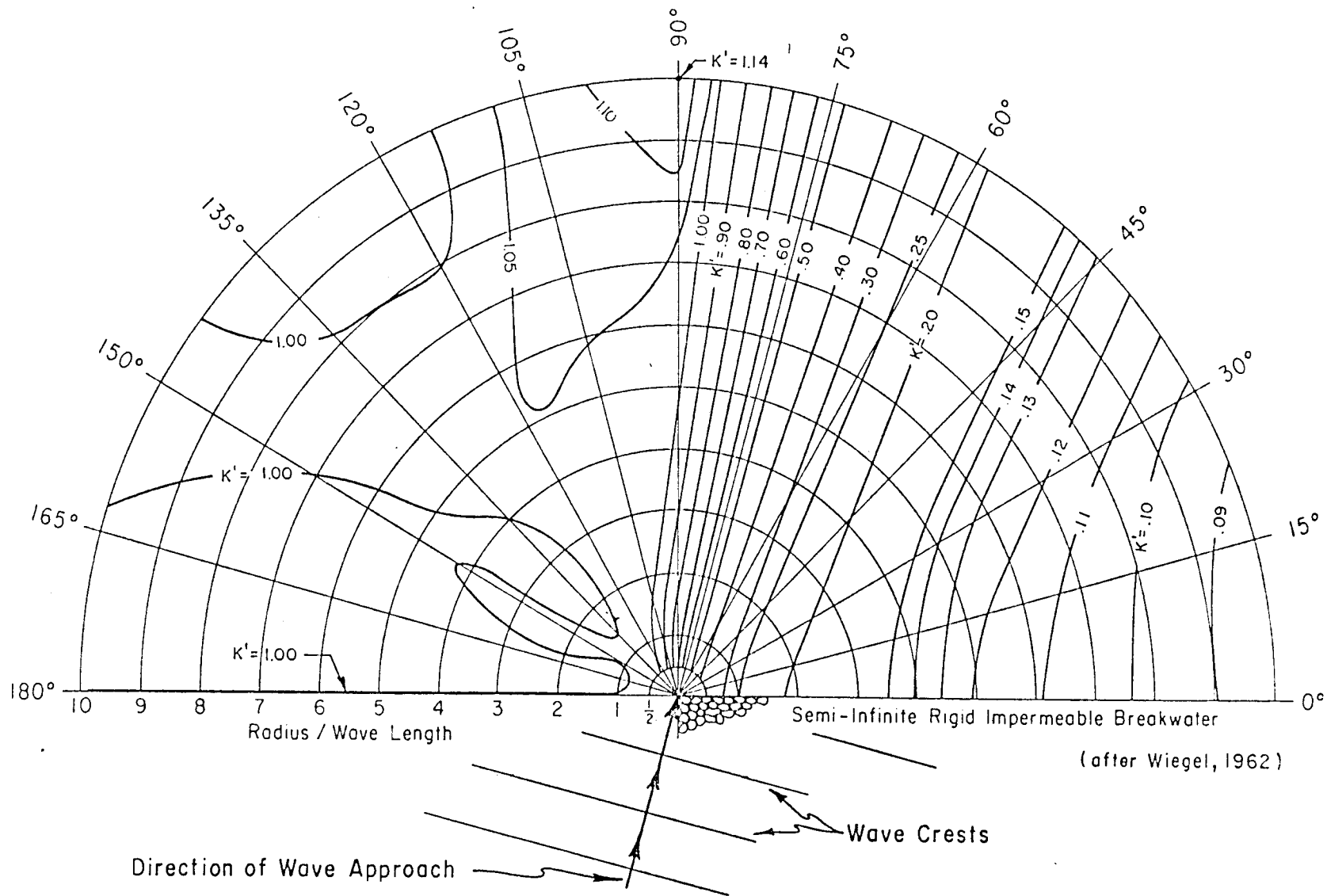


Figure B-5 Wave Diffraction Diagram - 75° Wave Angle

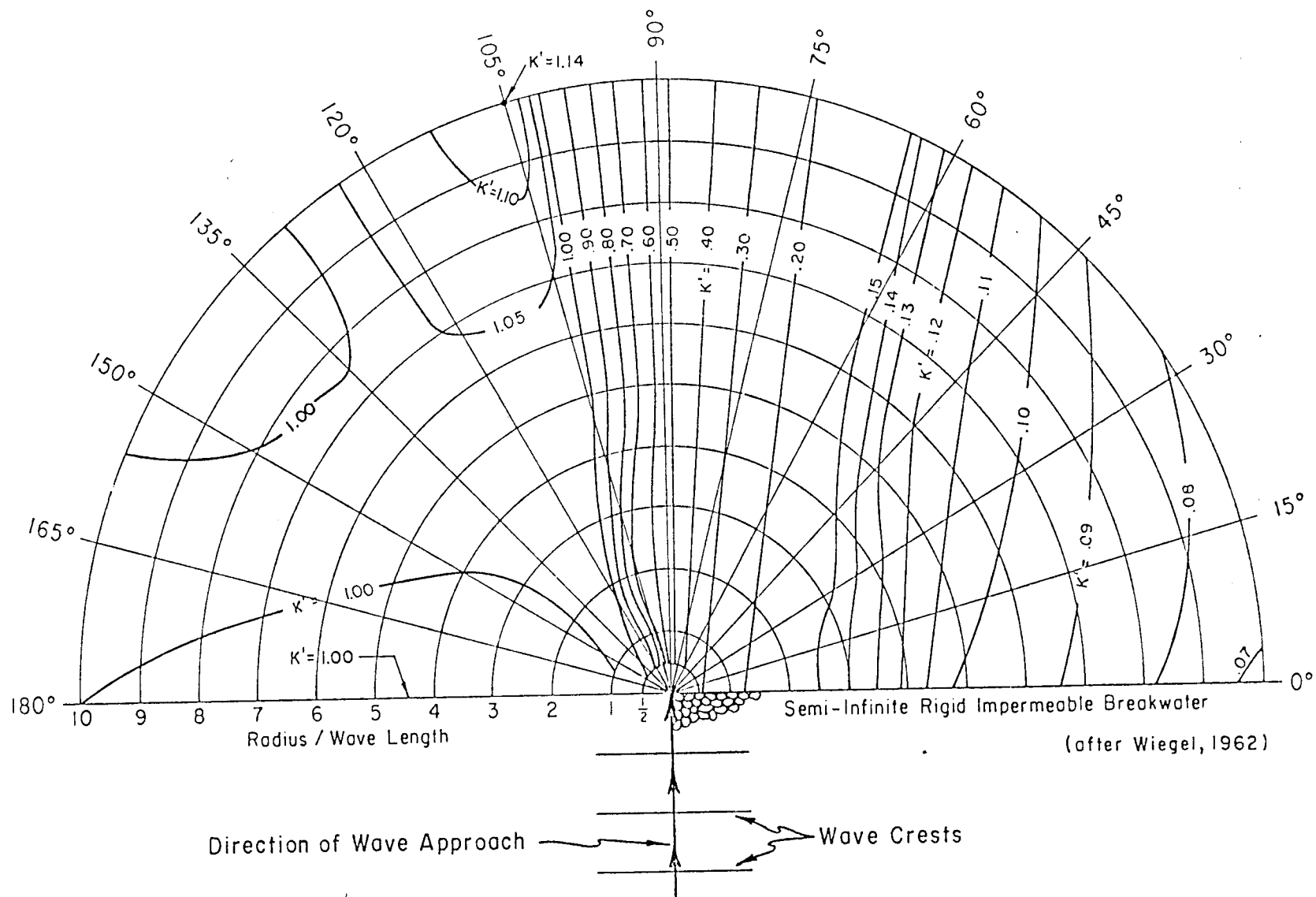


Figure B-6 . Wave Diffraction Diagram - 90° Wave Angle

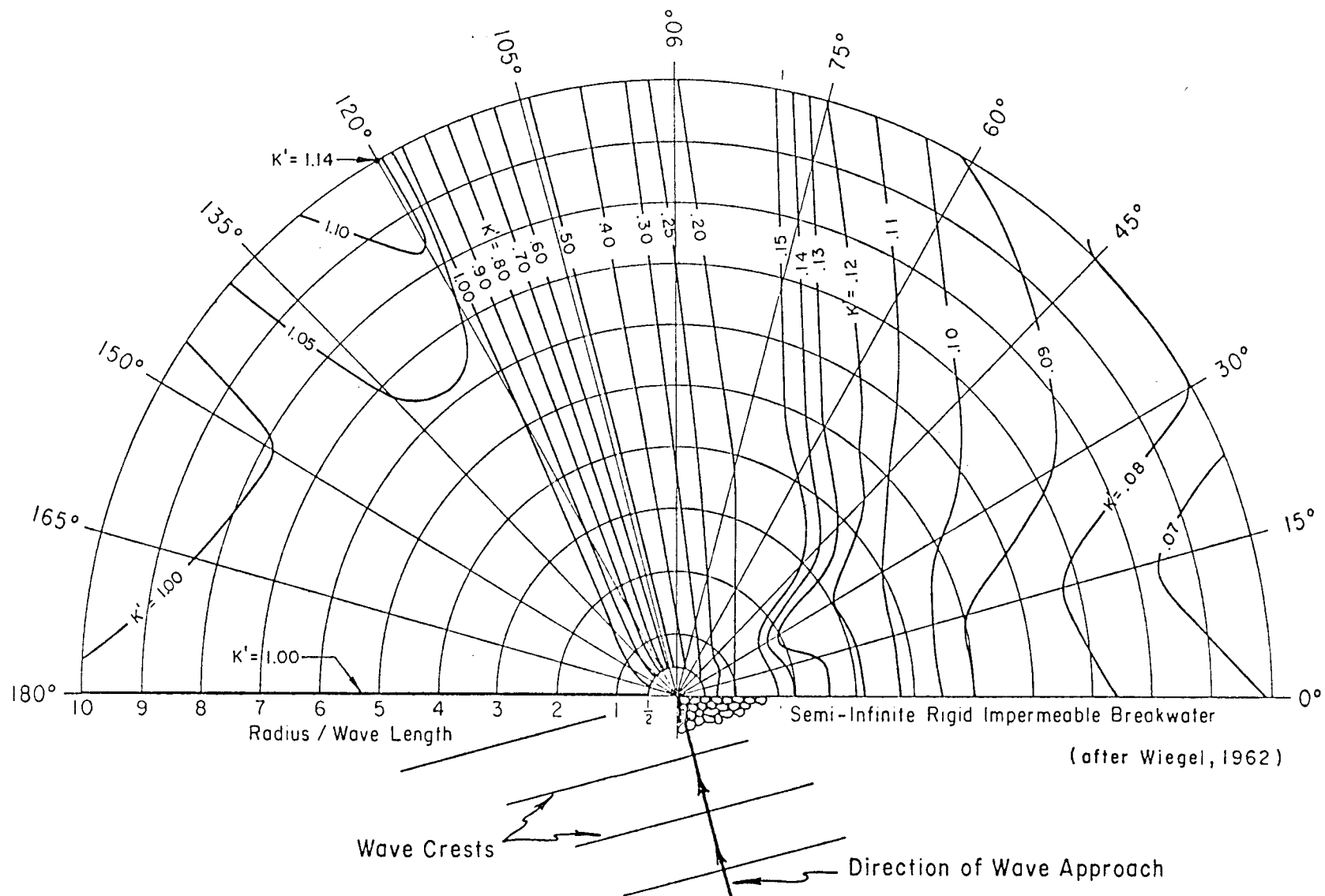


Figure B-7 Wave Diffraction Diagram - 105° Wave Angle

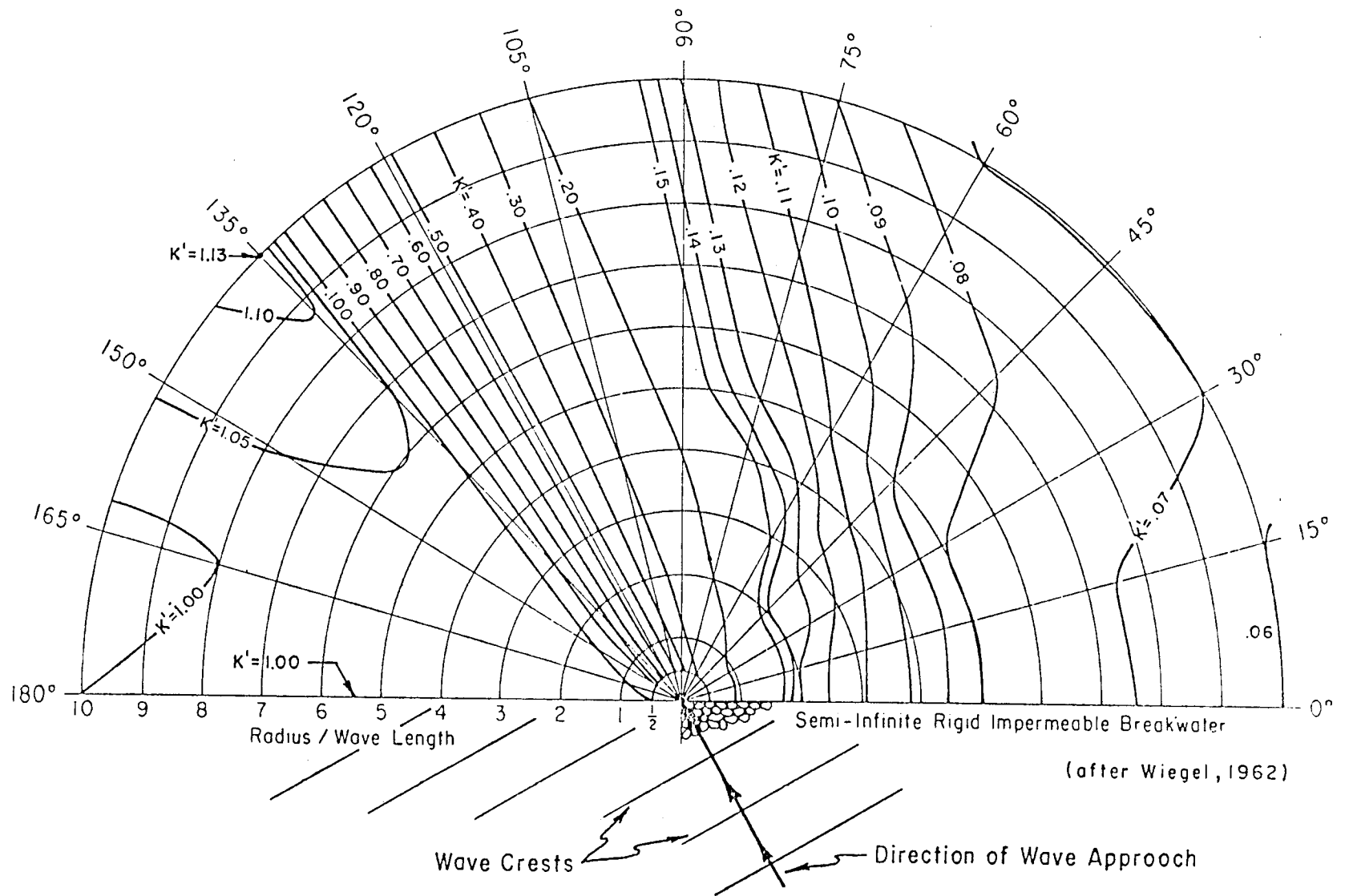


Figure B-8 Wave Diffraction Diagram - 120° Wave Angle

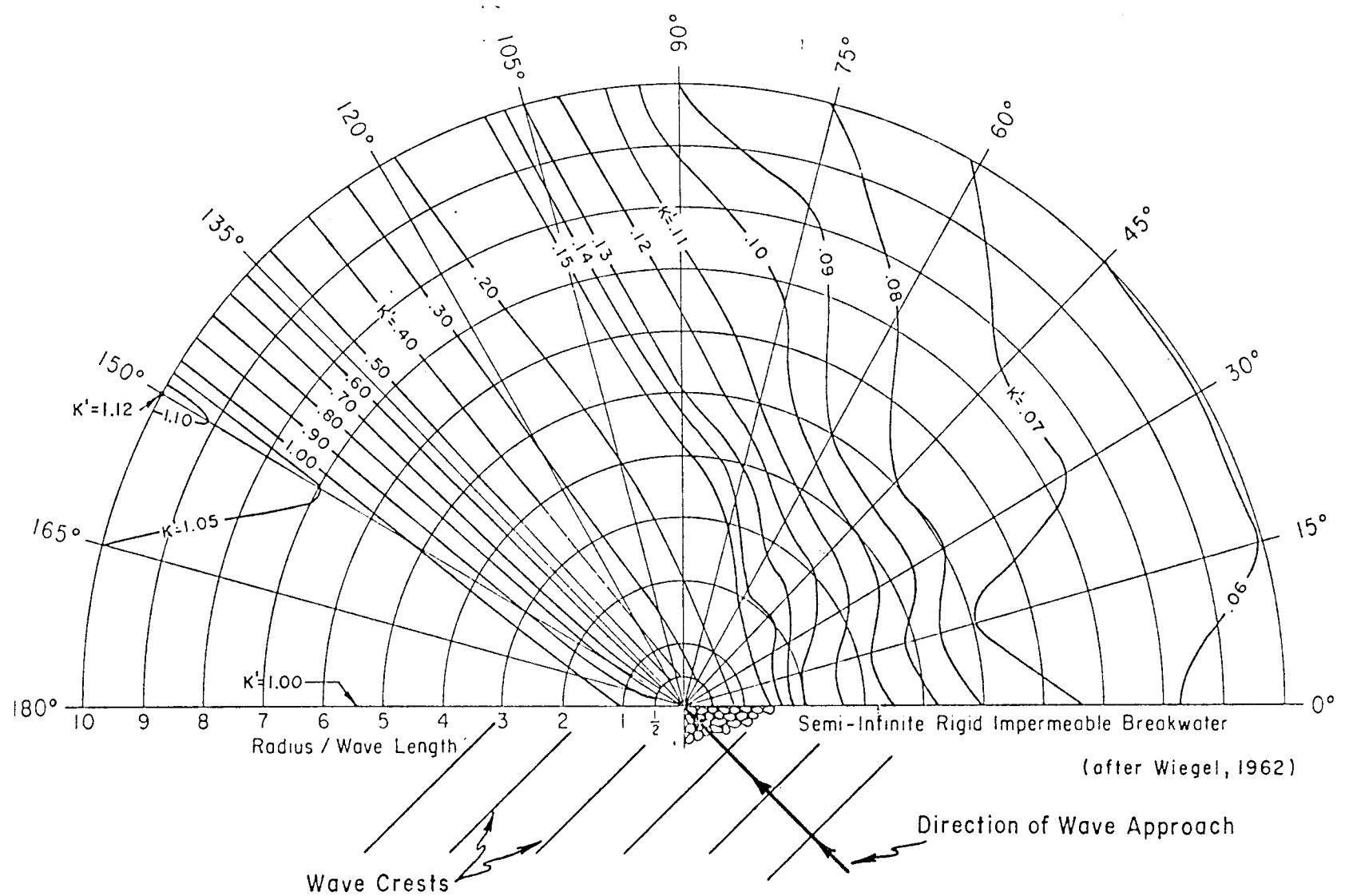


Figure B- 9 Wave Diffraction Diagram - 135° Wave Angle

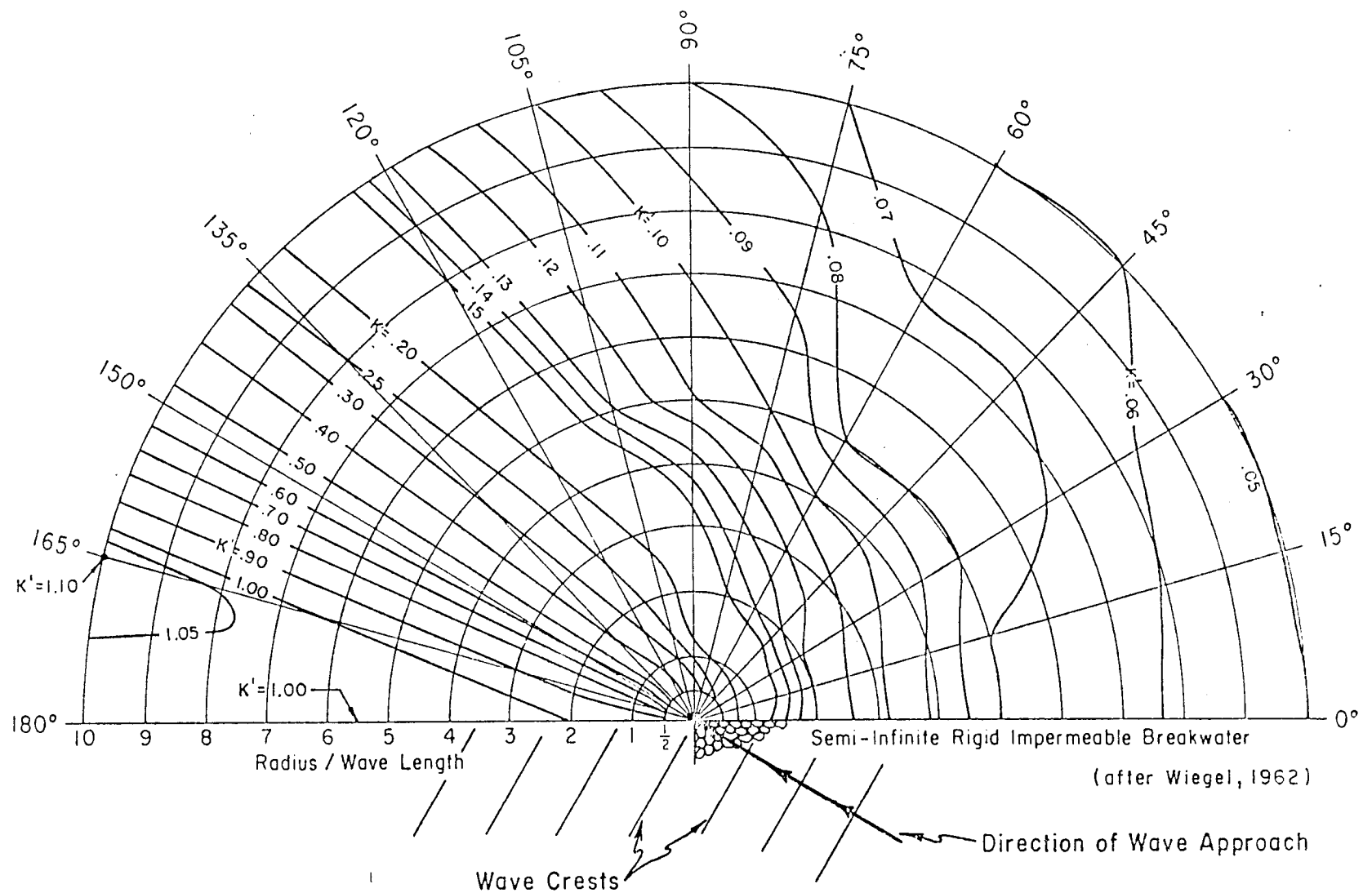


Figure B-10 Wave Diffraction Diagram - 150° Wave Angle

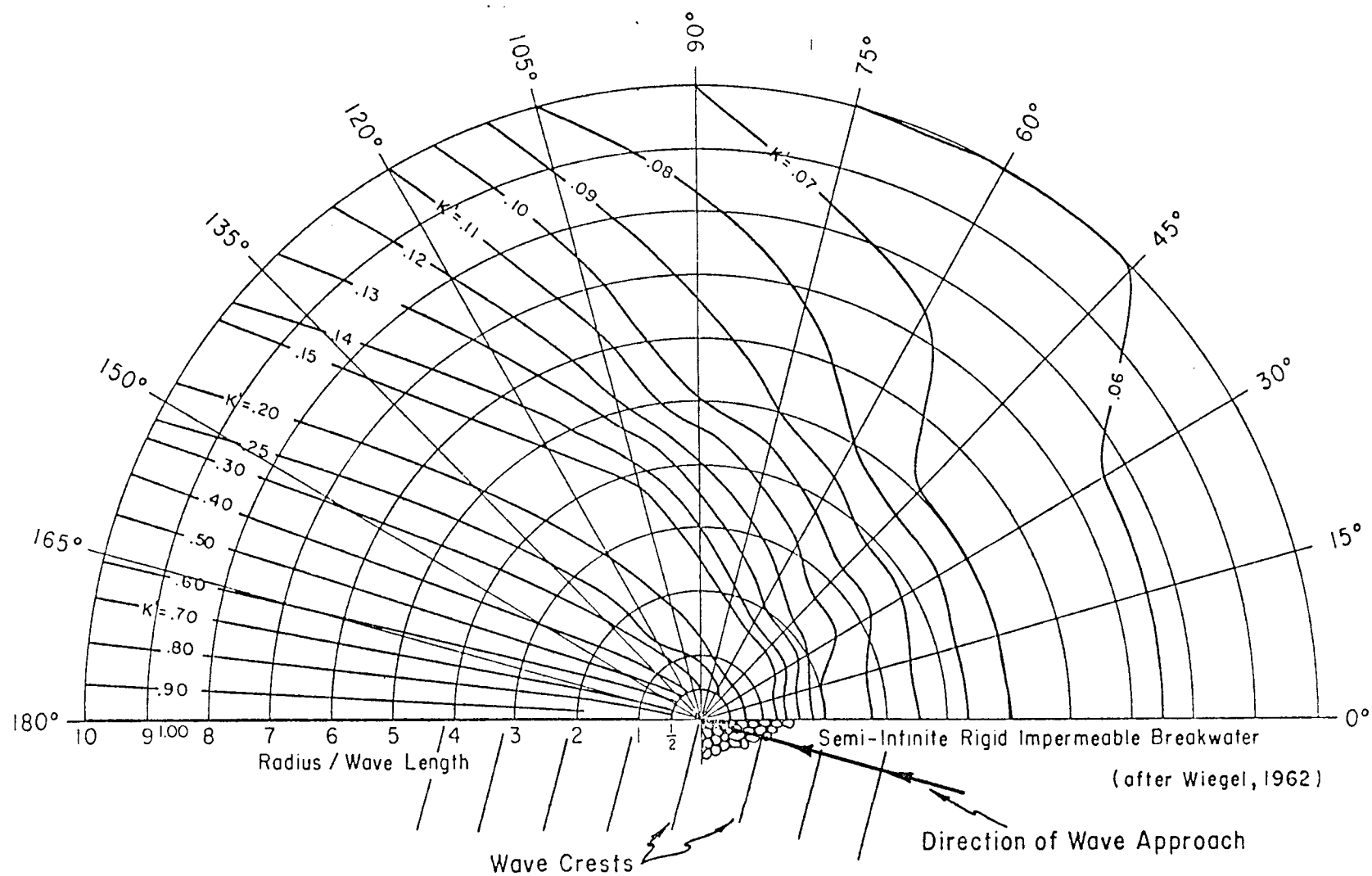


Figure B-11 Wave Diffraction Diagram - 165° Wave Angle

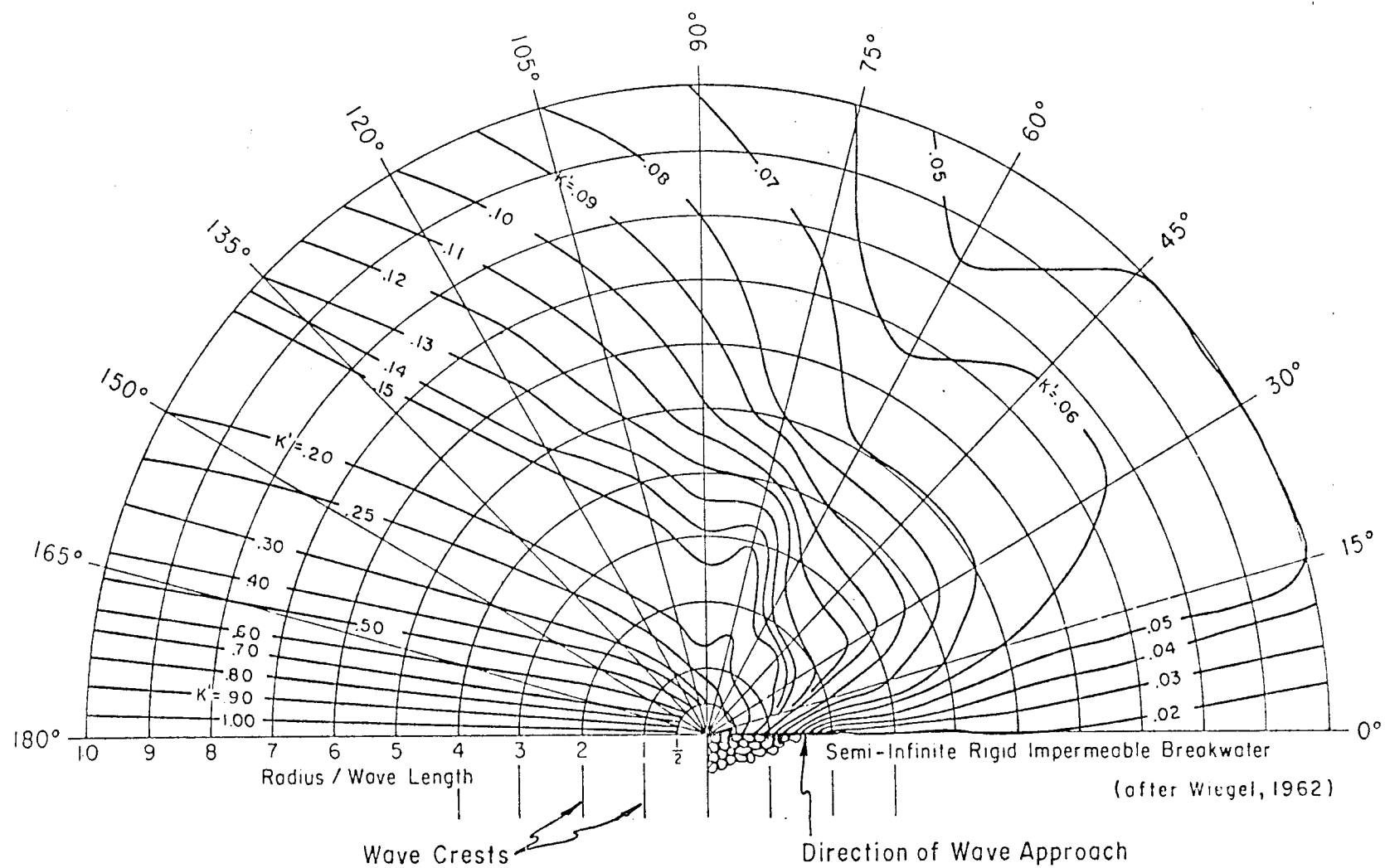


Figure B-12. Wave Diffraction Diagram - 180° Wave Angle

APPENDIX C

Functions of $2\pi d/L$

kd	d/L	d/dL*1	sinh kd	cosh kd	tanh kd
0.25	0.0098	0.0016	0.2526	1.0314	0.2449
0.26	0.0414	0.0017	0.2629	1.0340	0.2543
0.27	0.0430	0.0018	0.2733	1.0367	0.2636
0.28	0.0446	0.0019	0.2837	1.0395	0.2729
0.29	0.0462	0.0021	0.2941	1.0423	0.2821
0.30	0.0477	0.0022	0.3045	1.0453	0.2913
0.31	0.0494	0.0024	0.3150	1.0484	0.3004
0.32	0.0509	0.0025	0.3255	1.0516	0.3095
0.33	0.0525	0.0027	0.3360	1.0549	0.3185
0.34	0.0541	0.0028	0.3466	1.0584	0.3275
0.35	0.0557	0.0030	0.3572	1.0619	0.3364
0.36	0.0573	0.0031	0.3678	1.0655	0.3452
0.37	0.0589	0.0033	0.3785	1.0692	0.3540
0.38	0.0605	0.0035	0.3892	1.0731	0.3627
0.39	0.0621	0.0037	0.4000	1.0770	0.3714
0.40	0.0637	0.0038	0.4108	1.0811	0.3799
0.41	0.0653	0.0040	0.4216	1.0852	0.3885
0.42	0.0668	0.0042	0.4325	1.0895	0.3969
0.43	0.0684	0.0044	0.4434	1.0939	0.4053
0.44	0.0700	0.0046	0.4543	1.0984	0.4136
0.45	0.0716	0.0048	0.4653	1.1030	0.4219
0.46	0.0732	0.0050	0.4764	1.1077	0.4301
0.47	0.0748	0.0052	0.4875	1.1125	0.4382
0.48	0.0764	0.0054	0.4986	1.1174	0.4462
0.49	0.0780	0.0056	0.5098	1.1225	0.4542
0.50	0.0796	0.0059	0.5211	1.1276	0.4621
0.51	0.0812	0.0061	0.5324	1.1329	0.4699
0.52	0.0828	0.0063	0.5438	1.1383	0.4777
0.53	0.0844	0.0065	0.5552	1.1438	0.4854
0.54	0.0859	0.0067	0.5666	1.1494	0.4930
0.55	0.0875	0.0070	0.5782	1.1551	0.5005
0.56	0.0891	0.0072	0.5897	1.1609	0.5080
0.57	0.0907	0.0074	0.6014	1.1669	0.5154
0.58	0.0923	0.0077	0.6131	1.1730	0.5227
0.59	0.0939	0.0079	0.6248	1.1792	0.5299
0.60	0.0955	0.0082	0.6367	1.1855	0.5370
0.61	0.0971	0.0084	0.6485	1.1919	0.5441
0.62	0.0987	0.0087	0.6605	1.1984	0.5511
0.63	0.1003	0.0089	0.6725	1.2051	0.5581
0.64	0.1019	0.0092	0.6846	1.2119	0.5649
0.65	0.1035	0.0094	0.6967	1.2188	0.5717
0.66	0.1050	0.0097	0.7090	1.2258	0.5784
0.67	0.1066	0.0099	0.7213	1.2330	0.5850
0.68	0.1082	0.0102	0.7336	1.2402	0.5915
0.69	0.1098	0.0105	0.7461	1.2476	0.5980
0.70	0.1114	0.0107	0.7586	1.2552	0.6044
0.71	0.1130	0.0110	0.7712	1.2628	0.6107
0.72	0.1146	0.0113	0.7838	1.2706	0.6169
0.73	0.1162	0.0115	0.7966	1.2785	0.6231
0.74	0.1178	0.0118	0.8094	1.2865	0.6291
0.75	0.1194	0.0121	0.8223	1.2947	0.6351
0.76	0.1210	0.0123	0.8353	1.3030	0.6411
0.77	0.1226	0.0126	0.8484	1.3114	0.6470
0.78	0.1242	0.0128	0.8615	1.3199	0.6529

0.79	0.1257	0.0132	0.8749	1.3286	0.6584
0.80	0.1273	0.0135	0.8881	1.3374	0.6640
0.81	0.1289	0.0137	0.9015	1.3464	0.6696
0.82	0.1305	0.0140	0.9150	1.3555	0.6751
0.83	0.1321	0.0143	0.9286	1.3647	0.6805
0.84	0.1337	0.0146	0.9423	1.3740	0.6858
0.85	0.1353	0.0149	0.9561	1.3835	0.6911
0.86	0.1369	0.0152	0.9700	1.3932	0.6963
0.87	0.1385	0.0155	0.9840	1.4029	0.7014
0.88	0.1401	0.0157	0.9981	1.4128	0.7064
0.89	0.1416	0.0160	1.0122	1.4229	0.7114
0.90	0.1432	0.0163	1.0265	1.4331	0.7163
0.91	0.1448	0.0166	1.0409	1.4434	0.7211
0.92	0.1464	0.0169	1.0554	1.4539	0.7259
0.93	0.1480	0.0172	1.0700	1.4645	0.7306
0.94	0.1496	0.0175	1.0847	1.4753	0.7352
0.95	0.1512	0.0178	1.0995	1.4862	0.7398
0.96	0.1528	0.0181	1.1144	1.4973	0.7443
0.97	0.1544	0.0184	1.1294	1.5085	0.7487
0.98	0.1560	0.0187	1.1446	1.5199	0.7531
0.99	0.1576	0.0190	1.1598	1.5314	0.7574
1.00	0.1592	0.0193	1.1752	1.5431	0.7616
1.01	0.1607	0.0196	1.1907	1.5549	0.7658
1.02	0.1623	0.0199	1.2063	1.5669	0.7699
1.03	0.1639	0.0202	1.2220	1.5790	0.7739
1.04	0.1655	0.0205	1.2379	1.5913	0.7779
1.05	0.1671	0.0208	1.2539	1.6038	0.7818
1.06	0.1687	0.0211	1.2700	1.6164	0.7857
1.07	0.1703	0.0214	1.2862	1.6292	0.7895
1.08	0.1719	0.0217	1.3025	1.6421	0.7932
1.09	0.1735	0.0220	1.3190	1.6552	0.7969
1.10	0.1751	0.0223	1.3356	1.6685	0.8005
1.11	0.1767	0.0226	1.3524	1.6820	0.8041
1.12	0.1783	0.0229	1.3693	1.6956	0.8076
1.13	0.1798	0.0232	1.3863	1.7093	0.8110
1.14	0.1814	0.0235	1.4035	1.7233	0.8144
1.15	0.1830	0.0238	1.4208	1.7374	0.8178
1.16	0.1846	0.0241	1.4382	1.7517	0.8210
1.17	0.1862	0.0244	1.4558	1.7662	0.8243
1.18	0.1878	0.0247	1.4735	1.7808	0.8275
1.19	0.1894	0.0250	1.4914	1.7957	0.8306
1.20	0.1910	0.0253	1.5095	1.8107	0.8337
1.21	0.1926	0.0256	1.5276	1.8258	0.8367
1.22	0.1942	0.0259	1.5460	1.8412	0.8397
1.23	0.1958	0.0263	1.5645	1.8568	0.8426
1.24	0.1974	0.0266	1.5831	1.8725	0.8455
1.25	0.1989	0.0269	1.6019	1.8884	0.8483
1.26	0.2005	0.0272	1.6209	1.9045	0.8511
1.27	0.2021	0.0275	1.6400	1.9208	0.8538
1.28	0.2037	0.0278	1.6593	1.9373	0.8565
1.29	0.2053	0.0281	1.6788	1.9540	0.8591
1.30	0.2069	0.0284	1.6984	1.9709	0.8617
1.31	0.2085	0.0287	1.7182	1.9880	0.8643
1.32	0.2101	0.0290	1.7381	2.0053	0.8668
1.33	0.2117	0.0293	1.7581	2.0228	0.8692
1.34	0.2133	0.0296	1.7782	2.0404	0.8717

1.35	0.2149	0.0299	1.7991	2.0583	0.8741
1.36	0.2165	0.0302	1.8198	2.0764	0.8764
1.37	0.2180	0.0305	1.8406	2.0947	0.8787
1.38	0.2196	0.0308	1.8617	2.1132	0.8810
1.39	0.2212	0.0311	1.8829	2.1320	0.8832
1.40	0.2228	0.0314	1.9043	2.1509	0.8854
1.41	0.2244	0.0317	1.9259	2.1700	0.8875
1.42	0.2260	0.0320	1.9477	2.1894	0.8896
1.43	0.2276	0.0323	1.9697	2.2090	0.8917
1.44	0.2292	0.0326	1.9919	2.2288	0.8937
1.45	0.2308	0.0329	2.0143	2.2488	0.8957
1.46	0.2324	0.0332	2.0369	2.2691	0.8977
1.47	0.2340	0.0335	2.0597	2.2896	0.8996
1.48	0.2355	0.0338	2.0827	2.3103	0.9015
1.49	0.2371	0.0341	2.1059	2.3312	0.9033
1.50	0.2387	0.0344	2.1293	2.3524	0.9051
1.51	0.2403	0.0347	2.1529	2.3738	0.9069
1.52	0.2419	0.0350	2.1768	2.3955	0.9087
1.53	0.2435	0.0353	2.2008	2.4174	0.9104
1.54	0.2451	0.0356	2.2251	2.4395	0.9121
1.55	0.2467	0.0359	2.2496	2.4619	0.9138
1.56	0.2483	0.0362	2.2743	2.4845	0.9154
1.57	0.2499	0.0365	2.2993	2.5073	0.9170
1.58	0.2515	0.0368	2.3245	2.5305	0.9186
1.59	0.2531	0.0371	2.3499	2.5538	0.9201
1.60	0.2546	0.0374	2.3756	2.5775	0.9217
1.61	0.2562	0.0376	2.4015	2.6013	0.9232
1.62	0.2578	0.0379	2.4276	2.6255	0.9246
1.63	0.2594	0.0382	2.4540	2.6499	0.9261
1.64	0.2610	0.0385	2.4806	2.6746	0.9275
1.65	0.2626	0.0388	2.5075	2.6995	0.9289
1.66	0.2642	0.0391	2.5346	2.7247	0.9302
1.67	0.2658	0.0394	2.5620	2.7502	0.9316
1.68	0.2674	0.0397	2.5896	2.7760	0.9329
1.69	0.2690	0.0400	2.6175	2.8020	0.9341
1.70	0.2706	0.0403	2.6456	2.8283	0.9354
1.71	0.2722	0.0406	2.6740	2.8549	0.9366
1.72	0.2737	0.0409	2.7027	2.8818	0.9379
1.73	0.2753	0.0412	2.7317	2.9090	0.9391
1.74	0.2769	0.0414	2.7609	2.9364	0.9402
1.75	0.2785	0.0417	2.7904	2.9642	0.9414
1.76	0.2801	0.0420	2.8202	2.9922	0.9425
1.77	0.2817	0.0423	2.8503	3.0206	0.9436
1.78	0.2833	0.0426	2.8806	3.0492	0.9447
1.79	0.2849	0.0429	2.9112	3.0782	0.9458
1.80	0.2865	0.0432	2.9422	3.1075	0.9468
1.81	0.2881	0.0435	2.9734	3.1371	0.9478
1.82	0.2897	0.0437	3.0049	3.1669	0.9488
1.83	0.2913	0.0440	3.0367	3.1972	0.9498
1.84	0.2928	0.0443	3.0689	3.2277	0.9508
1.85	0.2944	0.0446	3.1013	3.2585	0.9517
1.86	0.2960	0.0449	3.1340	3.2897	0.9527
1.87	0.2976	0.0452	3.1671	3.3212	0.9536
1.88	0.2992	0.0455	3.2005	3.3530	0.9545
1.89	0.3008	0.0457	3.2341	3.3852	0.9554
1.90	0.3024	0.0460	3.2681	3.4177	0.9562

1.91	0.3040	0.0463	3.3025	3.4506	0.9571
1.92	0.3056	0.0466	3.3372	3.4838	0.9579
1.93	0.3072	0.0469	3.3722	3.5173	0.9587
1.94	0.3088	0.0472	3.4075	3.5512	0.9595
1.95	0.3104	0.0474	3.4432	3.5855	0.9603
1.96	0.3119	0.0477	3.4792	3.6201	0.9611
1.97	0.3135	0.0480	3.5156	3.6551	0.9618
1.98	0.3151	0.0483	3.5523	3.6904	0.9626
1.99	0.3167	0.0486	3.5894	3.7261	0.9633
2.00	0.3183	0.0488	3.6269	3.7622	0.9640
2.01	0.3199	0.0491	3.6647	3.7987	0.9647
2.02	0.3215	0.0494	3.7028	3.8355	0.9654
2.03	0.3231	0.0497	3.7414	3.8727	0.9661
2.04	0.3247	0.0500	3.7803	3.9103	0.9667
2.05	0.3263	0.0502	3.8196	3.9483	0.9674
2.06	0.3279	0.0505	3.8593	3.9867	0.9680
2.07	0.3295	0.0508	3.8993	4.0255	0.9687
2.08	0.3310	0.0511	3.9398	4.0647	0.9693
2.09	0.3326	0.0513	3.9806	4.1043	0.9699
2.10	0.3342	0.0516	4.0219	4.1443	0.9705
2.11	0.3358	0.0519	4.0635	4.1847	0.9710
2.12	0.3374	0.0522	4.1056	4.2256	0.9716
2.13	0.3390	0.0525	4.1480	4.2669	0.9721
2.14	0.3406	0.0527	4.1909	4.3085	0.9727
2.15	0.3422	0.0530	4.2342	4.3507	0.9732
2.16	0.3438	0.0533	4.2779	4.3932	0.9737
2.17	0.3454	0.0536	4.3221	4.4362	0.9743
2.18	0.3470	0.0538	4.3666	4.4797	0.9748
2.19	0.3485	0.0541	4.4116	4.5236	0.9753
2.20	0.3501	0.0544	4.4571	4.5679	0.9757
2.21	0.3517	0.0546	4.5030	4.6127	0.9762
2.22	0.3533	0.0549	4.5494	4.6580	0.9767
2.23	0.3549	0.0552	4.5962	4.7037	0.9771
2.24	0.3565	0.0555	4.6434	4.7499	0.9776
2.25	0.3581	0.0557	4.6912	4.7966	0.9780
2.26	0.3597	0.0560	4.7394	4.8437	0.9785
2.27	0.3613	0.0563	4.7880	4.8914	0.9789
2.28	0.3629	0.0566	4.8372	4.9395	0.9793
2.29	0.3645	0.0568	4.8868	4.9881	0.9797
2.30	0.3661	0.0571	4.9370	5.0372	0.9801
2.31	0.3676	0.0574	4.9876	5.0868	0.9805
2.32	0.3692	0.0576	5.0387	5.1370	0.9809
2.33	0.3708	0.0579	5.0903	5.1876	0.9812
2.34	0.3724	0.0582	5.1425	5.2388	0.9816
2.35	0.3740	0.0585	5.1951	5.2905	0.9820
2.36	0.3756	0.0587	5.2483	5.3427	0.9823
2.37	0.3772	0.0590	5.3020	5.3954	0.9827
2.38	0.3788	0.0593	5.3562	5.4487	0.9830
2.39	0.3804	0.0595	5.4109	5.5026	0.9833
2.40	0.3820	0.0598	5.4662	5.5569	0.9837
2.41	0.3836	0.0601	5.5221	5.6119	0.9840
2.42	0.3852	0.0603	5.5785	5.6674	0.9843
2.43	0.3867	0.0606	5.6354	5.7235	0.9846
2.44	0.3883	0.0609	5.6929	5.7801	0.9849
2.45	0.3899	0.0611	5.7510	5.8373	0.9852
2.46	0.3915	0.0614	5.8097	5.8951	0.9855

2.47	0.3931	0.0617	5.8689	5.9535	0.9852
2.48	0.3947	0.0619	5.9228	6.0125	0.9861
2.49	0.3963	0.0622	5.9892	6.0721	0.9863
2.50	0.3979	0.0625	6.0502	6.1323	0.9866
2.51	0.3995	0.0627	6.1118	6.1931	0.9869
2.52	0.4011	0.0630	6.1741	6.2545	0.9871
2.53	0.4027	0.0633	6.2369	6.3166	0.9874
2.54	0.4043	0.0635	6.3004	6.3793	0.9876
2.55	0.4058	0.0638	6.3645	6.4426	0.9879
2.56	0.4074	0.0641	6.4293	6.5066	0.9881
2.57	0.4090	0.0643	6.4946	6.5712	0.9884
2.58	0.4106	0.0646	6.5607	6.6365	0.9886
2.59	0.4122	0.0649	6.6274	6.7024	0.9888
2.60	0.4138	0.0651	6.6947	6.7690	0.9890
2.61	0.4154	0.0654	6.7628	6.8363	0.9892
2.62	0.4170	0.0657	6.8315	6.9043	0.9895
2.63	0.4186	0.0659	6.9008	6.9729	0.9897
2.64	0.4202	0.0662	6.9709	7.0423	0.9899
2.65	0.4218	0.0665	7.0417	7.1123	0.9901
2.66	0.4234	0.0667	7.1132	7.1831	0.9903
2.67	0.4249	0.0670	7.1854	7.2546	0.9905
2.68	0.4265	0.0672	7.2583	7.3268	0.9906
2.69	0.4281	0.0675	7.3319	7.3998	0.9908
2.70	0.4297	0.0678	7.4063	7.4735	0.9910
2.71	0.4313	0.0680	7.4814	7.5479	0.9912
2.72	0.4329	0.0683	7.5572	7.6231	0.9914
2.73	0.4345	0.0686	7.6338	7.6991	0.9915
2.74	0.4361	0.0688	7.7112	7.7758	0.9917
2.75	0.4377	0.0691	7.7894	7.8533	0.9919
2.76	0.4393	0.0694	7.8683	7.9316	0.9920
2.77	0.4409	0.0696	7.9480	8.0106	0.9922
2.78	0.4425	0.0699	8.0285	8.0905	0.9923
2.79	0.4440	0.0701	8.1098	8.1712	0.9925
2.80	0.4456	0.0704	8.1919	8.2527	0.9926
2.81	0.4472	0.0707	8.2749	8.3351	0.9928
2.82	0.4488	0.0709	8.3586	8.4182	0.9929
2.83	0.4504	0.0712	8.4432	8.5022	0.9931
2.84	0.4520	0.0714	8.5287	8.5871	0.9932
2.85	0.4536	0.0717	8.6150	8.6728	0.9933
2.86	0.4552	0.0720	8.7021	8.7594	0.9935
2.87	0.4568	0.0722	8.7902	8.8469	0.9936
2.88	0.4584	0.0725	8.8791	8.9352	0.9937
2.89	0.4600	0.0728	8.9689	9.0244	0.9938
2.90	0.4615	0.0730	9.0596	9.1146	0.9940
2.91	0.4631	0.0733	9.1512	9.2056	0.9941
2.92	0.4647	0.0735	9.2437	9.2976	0.9942
2.93	0.4663	0.0738	9.3371	9.3905	0.9943
2.94	0.4679	0.0741	9.4315	9.4844	0.9944
2.95	0.4695	0.0743	9.5268	9.5791	0.9945
2.96	0.4711	0.0746	9.6231	9.6749	0.9946
2.97	0.4727	0.0748	9.7203	9.7716	0.9947
2.98	0.4743	0.0751	9.8185	9.8693	0.9949
2.99	0.4759	0.0754	9.9177	9.9680	0.9950
3.00	0.4775	0.0756	10.0179	10.0677	0.9951
3.01	0.4791	0.0759	10.1191	10.1683	0.9952
3.02	0.4806	0.0761	10.2207	10.2699	0.9953

3.03	0.4822	0.0764	10.3245	10.3728	0.9953
3.04	0.4838	0.0767	10.4287	10.4765	0.9954
3.05	0.4854	0.0769	10.5340	10.5814	0.9955
3.06	0.4870	0.0772	10.6403	10.6872	0.9956
3.07	0.4886	0.0774	10.7477	10.7942	0.9957
3.08	0.4902	0.0777	10.8562	10.9022	0.9958
3.09	0.4918	0.0779	10.9658	11.0113	0.9959
3.10	0.4934	0.0782	11.0765	11.1215	0.9959
3.11	0.4950	0.0785	11.1882	11.2328	0.9960
3.12	0.4966	0.0787	11.3011	11.3453	0.9961
3.13	0.4982	0.0790	11.4151	11.4588	0.9962
3.14	0.4997	0.0792	11.5303	11.5736	0.9963
3.15	0.5013	0.0795	11.6466	11.6895	0.9963
3.16	0.5029	0.0798	11.7641	11.8065	0.9964
3.17	0.5045	0.0800	11.8827	11.9247	0.9965
3.18	0.5061	0.0803	12.0026	12.0442	0.9965
3.19	0.5077	0.0805	12.1236	12.1648	0.9966
3.20	0.5093	0.0808	12.2459	12.2866	0.9967
3.21	0.5109	0.0810	12.3694	12.4097	0.9967
3.22	0.5125	0.0813	12.4941	12.5340	0.9968
3.23	0.5141	0.0816	12.6200	12.6596	0.9969
3.24	0.5157	0.0818	12.7473	12.7864	0.9969
3.25	0.5173	0.0821	12.8758	12.9146	0.9970
3.26	0.5188	0.0823	13.0056	13.0440	0.9971
3.27	0.5204	0.0826	13.1367	13.1747	0.9971
3.28	0.5220	0.0828	13.2691	13.3067	0.9972
3.29	0.5236	0.0831	13.4028	13.4401	0.9972
3.30	0.5252	0.0834	13.5379	13.5748	0.9973
3.31	0.5268	0.0836	13.6743	13.7108	0.9973
3.32	0.5284	0.0839	13.8121	13.8483	0.9974
3.33	0.5300	0.0841	13.9513	13.9871	0.9974
3.34	0.5316	0.0844	14.0918	14.1273	0.9975
3.35	0.5332	0.0846	14.2338	14.2689	0.9975
3.36	0.5348	0.0849	14.3772	14.4120	0.9976
3.37	0.5364	0.0852	14.5221	14.5565	0.9976
3.38	0.5379	0.0854	14.6684	14.7024	0.9977
3.39	0.5395	0.0857	14.8161	14.8498	0.9977
3.40	0.5411	0.0859	14.9654	14.9987	0.9978
3.41	0.5427	0.0862	15.1161	15.1491	0.9978
3.42	0.5443	0.0864	15.2684	15.3011	0.9979
3.43	0.5459	0.0867	15.4221	15.4545	0.9979
3.44	0.5475	0.0870	15.5774	15.6095	0.9979
3.45	0.5491	0.0872	15.7343	15.7661	0.9980
3.46	0.5507	0.0875	15.8928	15.9242	0.9980
3.47	0.5523	0.0877	16.0528	16.0839	0.9981
3.48	0.5539	0.0880	16.2145	16.2453	0.9981
3.49	0.5555	0.0882	16.3777	16.4082	0.9981
3.50	0.5570	0.0885	16.5426	16.5728	0.9982
3.51	0.5586	0.0888	16.7092	16.7391	0.9982
3.52	0.5602	0.0890	16.8774	16.9070	0.9982
3.53	0.5618	0.0893	17.0473	17.0766	0.9983
3.54	0.5634	0.0895	17.2190	17.2480	0.9983
3.55	0.5650	0.0898	17.3923	17.4210	0.9984
3.56	0.5666	0.0900	17.5674	17.5953	0.9984
3.57	0.5682	0.0903	17.7442	17.7724	0.9984
3.58	0.5698	0.0905	17.9223	17.9500	0.9984

3.59	0.5714	0.0908	18.1032	18.1308	0.9985
3.60	0.5730	0.0911	18.2855	18.3128	0.9985
3.61	0.5745	0.0913	18.4695	18.4966	0.9985
3.62	0.5761	0.0916	18.6554	18.6822	0.9986
3.63	0.5777	0.0918	18.8432	18.8697	0.9986
3.64	0.5793	0.0921	19.0328	19.0590	0.9986
3.65	0.5809	0.0923	19.2243	19.2503	0.9986
3.66	0.5825	0.0926	19.4178	19.4435	0.9987
3.67	0.5841	0.0928	19.6132	19.6387	0.9987
3.68	0.5857	0.0931	19.8106	19.8358	0.9987
3.69	0.5873	0.0934	20.0099	20.0349	0.9988
3.70	0.5889	0.0936	20.2113	20.2360	0.9988
3.71	0.5905	0.0939	20.4147	20.4391	0.9988
3.72	0.5921	0.0941	20.6201	20.6443	0.9988
3.73	0.5936	0.0944	20.8276	20.8516	0.9988
3.74	0.5952	0.0946	21.0371	21.0609	0.9989
3.75	0.5968	0.0949	21.2488	21.2723	0.9989
3.76	0.5984	0.0951	21.4626	21.4859	0.9989
3.77	0.6000	0.0954	21.6785	21.7016	0.9989
3.78	0.6016	0.0956	21.8966	21.9194	0.9990
3.79	0.6032	0.0959	22.1169	22.1395	0.9990
3.80	0.6048	0.0962	22.3394	22.3618	0.9990
3.81	0.6064	0.0964	22.5641	22.5863	0.9990
3.82	0.6080	0.0967	22.7911	22.8131	0.9991
3.83	0.6096	0.0969	23.0204	23.0421	0.9991
3.84	0.6112	0.0972	23.2520	23.2735	0.9991
3.85	0.6127	0.0974	23.4859	23.5072	0.9991
3.86	0.6143	0.0977	23.7221	23.7432	0.9991
3.87	0.6159	0.0979	23.9608	23.9816	0.9991
3.88	0.6175	0.0982	24.2018	24.2224	0.9991
3.89	0.6191	0.0985	24.4452	24.4657	0.9992
3.90	0.6207	0.0987	24.6911	24.7113	0.9992
3.91	0.6223	0.0990	24.9395	24.9595	0.9992
3.92	0.6239	0.0992	25.1903	25.2101	0.9992
3.93	0.6255	0.0995	25.4437	25.4633	0.9992
3.94	0.6271	0.0997	25.6996	25.7190	0.9992
3.95	0.6287	0.1000	25.9581	25.9773	0.9993
3.96	0.6303	0.1002	26.2191	26.2382	0.9993
3.97	0.6318	0.1005	26.4828	26.5017	0.9993
3.98	0.6334	0.1007	26.7492	26.7679	0.9993
3.99	0.6350	0.1010	27.0182	27.0367	0.9993
4.00	0.6366	0.1013	27.2899	27.3082	0.9993
4.01	0.6382	0.1015	27.5644	27.5825	0.9993
4.02	0.6398	0.1018	27.8416	27.8595	0.9994
4.03	0.6414	0.1020	28.1216	28.1393	0.9994
4.04	0.6430	0.1023	28.4044	28.4220	0.9994
4.05	0.6446	0.1025	28.6900	28.7074	0.9994
4.06	0.6462	0.1028	28.9785	28.9958	0.9994
4.07	0.6478	0.1030	29.2699	29.2870	0.9994
4.08	0.6494	0.1033	29.5643	29.5812	0.9994
4.09	0.6509	0.1035	29.8616	29.8763	0.9994
4.10	0.6525	0.1038	30.1619	30.1764	0.9995
4.11	0.6541	0.1041	30.4652	30.4816	0.9995
4.12	0.6557	0.1043	30.7715	30.7877	0.9995
4.13	0.6573	0.1046	31.0807	31.0970	0.9995
4.14	0.6589	0.1048	31.3929	31.4094	0.9995

4.15	0.6605	0.1051	31.7091	31.7249	0.9995
4.16	0.6621	0.1053	32.0280	32.0436	0.9995
4.17	0.6637	0.1056	32.3500	32.3655	0.9995
4.18	0.6653	0.1058	32.6753	32.6906	0.9995
4.19	0.6669	0.1061	33.0038	33.0190	0.9995
4.20	0.6685	0.1063	33.3357	33.3507	0.9996
4.21	0.6700	0.1066	33.6708	33.6857	0.9996
4.22	0.6716	0.1068	34.0094	34.0241	0.9996
4.23	0.6732	0.1071	34.3513	34.3659	0.9996
4.24	0.6748	0.1074	34.6967	34.7111	0.9996
4.25	0.6764	0.1076	35.0456	35.0598	0.9996
4.26	0.6780	0.1079	35.3979	35.4121	0.9996
4.27	0.6796	0.1081	35.7538	35.7678	0.9996
4.28	0.6812	0.1084	36.1133	36.1271	0.9996
4.29	0.6828	0.1086	36.4764	36.4901	0.9996
4.30	0.6844	0.1089	36.8431	36.8567	0.9996
4.31	0.6860	0.1091	37.2135	37.2270	0.9996
4.32	0.6875	0.1094	37.5877	37.6010	0.9996
4.33	0.6891	0.1096	37.9656	37.9787	0.9997
4.34	0.6907	0.1099	38.3473	38.3603	0.9997
4.35	0.6923	0.1102	38.7328	38.7457	0.9997
4.36	0.6939	0.1104	39.1222	39.1350	0.9997
4.37	0.6955	0.1107	39.5155	39.5281	0.9997
4.38	0.6971	0.1109	39.9128	39.9253	0.9997
4.39	0.6987	0.1112	40.3140	40.3264	0.9997
4.40	0.7003	0.1114	40.7193	40.7316	0.9997
4.41	0.7019	0.1117	41.1287	41.1408	0.9997
4.42	0.7035	0.1119	41.5421	41.5542	0.9997
4.43	0.7051	0.1122	41.9598	41.9717	0.9997
4.44	0.7066	0.1124	42.3816	42.3934	0.9997
4.45	0.7082	0.1127	42.8076	42.8193	0.9997
4.46	0.7098	0.1129	43.2380	43.2495	0.9997
4.47	0.7114	0.1132	43.6726	43.6841	0.9997
4.48	0.7130	0.1135	44.1117	44.1230	0.9997
4.49	0.7146	0.1137	44.5551	44.5663	0.9997
4.50	0.7162	0.1140	45.0030	45.0141	0.9998
4.51	0.7178	0.1142	45.4554	45.4664	0.9998
4.52	0.7194	0.1145	45.9124	45.9232	0.9998
4.53	0.7210	0.1147	46.3739	46.3847	0.9998
4.54	0.7226	0.1150	46.8401	46.8507	0.9998
4.55	0.7242	0.1152	47.3109	47.3215	0.9998
4.56	0.7257	0.1155	47.7865	47.7970	0.9998
4.57	0.7273	0.1157	48.2669	48.2772	0.9998
4.58	0.7289	0.1160	48.7521	48.7623	0.9998
4.59	0.7305	0.1162	49.2421	49.2523	0.9998
4.60	0.7321	0.1165	49.7371	49.7472	0.9998
4.61	0.7337	0.1167	50.2371	50.2471	0.9998
4.62	0.7353	0.1170	50.7421	50.7519	0.9998
4.63	0.7369	0.1173	51.2522	51.2619	0.9998
4.64	0.7385	0.1175	51.7673	51.7770	0.9998
4.65	0.7401	0.1178	52.2877	52.2973	0.9998
4.66	0.7417	0.1180	52.8133	52.8228	0.9998
4.67	0.7433	0.1183	53.3442	53.3536	0.9998
4.68	0.7449	0.1185	53.8804	53.8897	0.9998
4.69	0.7464	0.1188	54.4229	54.4321	0.9998
4.70	0.7480	0.1190	54.9720	54.9811	0.9998

4.71	0.7496	0.1193	55.5216	55.5306	0.9993
4.72	0.7512	0.1195	56.0797	56.0886	0.9998
4.73	0.7528	0.1198	56.6434	56.6522	0.9998
4.74	0.7544	0.1200	57.2127	57.2215	0.9998
4.75	0.7560	0.1203	57.7878	57.7965	0.9999
4.76	0.7576	0.1206	58.3687	58.3772	0.9999
4.77	0.7592	0.1208	58.9554	58.9639	0.9999
4.78	0.7608	0.1211	59.5480	59.5564	0.9999
4.79	0.7624	0.1213	60.1465	60.1548	0.9999
4.80	0.7639	0.1216	60.7511	60.7593	0.9999
4.81	0.7655	0.1218	61.3617	61.3699	0.9999
4.82	0.7671	0.1221	61.9785	61.9866	0.9999
4.83	0.7687	0.1223	62.6015	62.6095	0.9999
4.84	0.7703	0.1226	63.2307	63.2386	0.9999
4.85	0.7719	0.1228	63.8663	63.8741	0.9999
4.86	0.7735	0.1231	64.5082	64.5160	0.9999
4.87	0.7751	0.1233	65.1566	65.1643	0.9999
4.88	0.7767	0.1236	65.8115	65.8191	0.9999
4.89	0.7783	0.1239	66.4730	66.4805	0.9999
4.90	0.7799	0.1241	67.1412	67.1486	0.9999
4.91	0.7815	0.1244	67.8160	67.8234	0.9999
4.92	0.7830	0.1246	68.4977	68.5050	0.9999
4.93	0.7846	0.1249	69.1861	69.1934	0.9999
4.94	0.7862	0.1251	69.8815	69.8887	0.9999
4.95	0.7878	0.1254	70.5839	70.5910	0.9999
4.96	0.7894	0.1256	71.2934	71.3004	0.9999
4.97	0.7910	0.1259	72.0100	72.0169	0.9999
4.98	0.7926	0.1261	72.7338	72.7406	0.9999
4.99	0.7942	0.1264	73.4648	73.4716	0.9999
5.00	0.7958	0.1266	74.2032	74.2099	0.9999

kd	d/L	d/ql*1	sinh kd	cosh kd
5.00	0.7958	0.1266	74.2032	74.2097
5.05	0.8037	0.1279	78.0080	78.0144
5.10	0.8117	0.1292	82.0079	82.0140
5.15	0.8196	0.1304	86.2128	86.2186
5.20	0.8276	0.1317	90.6334	90.6389
5.25	0.8356	0.1330	95.2805	95.2858
5.30	0.8435	0.1342	100.1659	100.1709
5.35	0.8515	0.1355	105.3018	105.3065
5.40	0.8594	0.1368	110.7009	110.7055
5.45	0.8674	0.1380	116.3769	116.3812
5.50	0.8754	0.1393	122.3439	122.3480
5.55	0.8833	0.1406	128.6168	128.6207
5.60	0.8913	0.1418	135.2114	135.2151
5.65	0.8992	0.1431	142.1440	142.1475
5.70	0.9072	0.1444	149.4320	149.4354
5.75	0.9151	0.1456	157.0937	157.0969
5.80	0.9231	0.1469	165.1483	165.1513
5.85	0.9311	0.1482	173.6158	173.6186
5.90	0.9390	0.1494	182.5174	182.5201
5.95	0.9470	0.1507	191.8754	191.8780
6.00	0.9549	0.1520	201.7132	201.7156
6.05	0.9629	0.1532	212.0553	212.0577
6.10	0.9708	0.1545	222.9278	222.9300
6.15	0.9788	0.1558	234.3576	234.3598
6.20	0.9868	0.1570	246.3735	246.3755
6.25	0.9947	0.1583	259.0054	259.0074
6.30	1.0027	0.1596	272.2850	272.2869
6.35	1.0106	0.1608	286.2455	286.2472
6.40	1.0186	0.1621	300.9217	300.9233
6.45	1.0265	0.1634	316.3504	316.3519
6.50	1.0345	0.1646	332.5701	332.5716
6.55	1.0425	0.1659	349.6214	349.6228
6.60	1.0504	0.1672	367.5469	367.5483
6.65	1.0584	0.1684	386.3915	386.3928
6.70	1.0663	0.1697	406.2023	406.2035
6.75	1.0743	0.1710	427.0288	427.0300
6.80	1.0823	0.1722	448.9231	448.9242
6.85	1.0902	0.1735	471.9399	471.9410
6.90	1.0982	0.1748	496.1369	496.1379
6.95	1.1061	0.1760	521.5744	521.5753
7.00	1.1141	0.1773	548.3161	548.3170
7.05	1.1220	0.1786	576.4289	576.4298
7.10	1.1300	0.1798	605.9831	605.9839
7.15	1.1380	0.1811	637.0526	637.0534
7.20	1.1459	0.1824	669.7150	669.7158
7.25	1.1539	0.1836	704.0521	704.0528
7.30	1.1618	0.1849	740.1496	740.1503
7.35	1.1698	0.1862	778.0779	778.0786
7.40	1.1777	0.1874	817.9919	817.9925
7.45	1.1857	0.1887	859.9313	859.9319
7.50	1.1937	0.1900	904.0209	904.0215
7.55	1.2016	0.1912	950.3711	950.3716
7.60	1.2096	0.1925	999.0977	999.0982
7.65	1.2175	0.1938	1050.3226	1050.3230

7.70	1.2255	0.1950	1104.1738	1104.1742
7.75	1.2335	0.1963	1160.7860	1160.7864
7.80	1.2414	0.1976	1220.3008	1220.3012
7.85	1.2494	0.1988	1282.8670	1282.8674
7.90	1.2573	0.2001	1348.6410	1348.6413
7.95	1.2653	0.2014	1417.7873	1417.7877
8.00	1.2732	0.2026	1490.4788	1490.4792
8.05	1.2812	0.2039	1566.8973	1566.8976
8.10	1.2892	0.2052	1647.2339	1647.2342
8.15	1.2971	0.2064	1731.6894	1731.6897
8.20	1.3051	0.2077	1820.4750	1820.4753
8.25	1.3130	0.2090	1913.8128	1913.8130
8.30	1.3210	0.2102	2011.9361	2011.9363
8.35	1.3289	0.2115	2115.0903	2115.0905
8.40	1.3369	0.2128	2223.5333	2223.5335
8.45	1.3449	0.2140	2337.5363	2337.5365
8.50	1.3528	0.2153	2457.3843	2457.3845
8.55	1.3608	0.2166	2583.3771	2583.3773
8.60	1.3687	0.2178	2715.8297	2715.8299
8.65	1.3767	0.2191	2855.0733	2855.0735
8.70	1.3846	0.2204	3001.4560	3001.4562
8.75	1.3926	0.2216	3155.3440	3155.3441
8.80	1.4006	0.2229	3317.1219	3317.1221
8.85	1.4085	0.2242	3487.1944	3487.1946
8.90	1.4165	0.2254	3665.9867	3665.9868
8.95	1.4244	0.2267	3853.9459	3853.9460
9.00	1.4324	0.2280	4051.5419	4051.5420
9.05	1.4404	0.2292	4259.2689	4259.2690
9.10	1.4483	0.2305	4477.6463	4477.6464
9.15	1.4563	0.2318	4707.2201	4707.2202
9.20	1.4642	0.2330	4948.5645	4948.5646
9.25	1.4722	0.2343	5202.2828	5202.2829
9.30	1.4801	0.2356	5469.0096	5469.0096
9.35	1.4881	0.2368	5749.4117	5749.4118
9.40	1.4961	0.2381	6044.1903	6044.1904
9.45	1.5040	0.2394	6354.0826	6354.0827
9.50	1.5120	0.2406	6679.8634	6679.8635
9.55	1.5199	0.2419	7022.3473	7022.3474
9.60	1.5279	0.2432	7382.3907	7382.3908
9.65	1.5358	0.2444	7760.8940	7760.8941
9.70	1.5438	0.2457	8158.8036	8158.8036
9.75	1.5518	0.2470	8577.1144	8577.1144
9.80	1.5597	0.2482	9016.8724	9016.8725
9.85	1.5677	0.2495	9479.1774	9479.1774
9.90	1.5756	0.2508	9965.1852	9965.1852
9.95	1.5836	0.2520	10476.1112	10476.1112
10.05	1.5995	0.2546	11577.8934	11577.8934
10.10	1.6075	0.2558	12171.5047	12171.5047
10.15	1.6154	0.2571	12795.5511	12795.5511
10.20	1.6234	0.2584	13451.5930	13451.5931
10.25	1.6313	0.2596	14141.2709	14141.2710
10.30	1.6393	0.2609	14866.3094	14866.3094
10.35	1.6473	0.2622	15628.5214	15628.5214
10.40	1.6552	0.2634	16429.8128	16429.8129
10.45	1.6632	0.2647	17272.1873	17272.1874
10.50	1.6711	0.2660	18157.7513	18157.7514

10.55	1.6791	0.2672	19088.7191	19088.7192
10.60	1.6870	0.2685	20067.4187	20067.4187
10.65	1.6950	0.2698	21096.2973	21096.2973
10.70	1.7030	0.2710	22177.9276	22177.9276
10.75	1.7109	0.2723	23315.0142	23315.0142
10.80	1.7189	0.2736	24510.4006	24510.4006
10.85	1.7268	0.2748	25767.0757	25767.0757
10.90	1.7348	0.2761	27088.1819	27088.1819
10.95	1.7427	0.2774	28477.0227	28477.0227
11.00	1.7507	0.2786	29937.0708	29937.0709
11.05	1.7587	0.2799	31471.9773	31471.9773
11.10	1.7666	0.2812	33085.5801	33085.5801
11.15	1.7746	0.2824	34781.9140	34781.9141
11.20	1.7825	0.2837	36565.2209	36565.2209
11.25	1.7905	0.2850	38439.9599	38439.9599
11.30	1.7985	0.2862	40410.8188	40410.8188
11.35	1.8064	0.2875	42482.7257	42482.7258
11.40	1.8144	0.2888	44660.8617	44660.8617
11.45	1.8223	0.2900	46950.6730	46950.6730
11.50	1.8303	0.2913	49357.8855	49357.8855
11.55	1.8382	0.2926	51888.5184	51888.5184
11.60	1.8462	0.2938	54548.8996	54548.8996
11.65	1.8542	0.2951	57345.6815	57345.6815
11.70	1.8621	0.2964	60285.8575	60285.8575
11.75	1.8701	0.2976	63376.7795	63376.7795
11.80	1.8780	0.2989	66626.1765	66626.1765
11.85	1.8860	0.3002	70042.1736	70042.1736
11.90	1.8939	0.3014	73633.3126	73633.3126
11.95	1.9019	0.3027	77408.5733	77408.5733
12.00	1.9099	0.3040	81377.3957	81377.3957
12.05	1.9178	0.3052	85549.7040	85549.7040
12.10	1.9258	0.3065	89935.9311	89935.9311
12.15	1.9337	0.3078	94547.0449	94547.0449
12.20	1.9417	0.3090	99394.5756	99394.5756
12.25	1.9496	0.3103	104490.6444	104490.6444
12.30	1.9576	0.3116	109847.9943	109847.9943
12.35	1.9656	0.3128	115480.0214	115480.0214
12.40	1.9735	0.3141	121400.8087	121400.8088
12.45	1.9815	0.3154	127625.1613	127625.1613
12.50	1.9894	0.3166	134168.6433	134168.6433
12.55	1.9974	0.3179	141047.6167	141047.6167
12.60	2.0054	0.3192	148279.2826	148279.2827
12.65	2.0133	0.3204	155881.7240	155881.7240
12.70	2.0213	0.3217	163873.9509	163873.9509
12.75	2.0292	0.3230	172275.9481	172275.9481
12.80	2.0372	0.3242	181108.7248	181108.7248
12.85	2.0451	0.3255	190394.3677	190394.3677
12.90	2.0531	0.3268	200156.0957	200156.0957
12.95	2.0611	0.3280	210418.3181	210418.3181
13.00	2.0690	0.3293	221206.6960	221206.6960
13.05	2.0770	0.3306	232548.2058	232548.2058
13.10	2.0849	0.3318	244471.2073	244471.2073
13.15	2.0929	0.3331	257005.5141	257005.5141
13.20	2.1008	0.3344	270182.4686	270182.4686
13.25	2.1088	0.3356	284035.0200	284035.0200
13.30	2.1168	0.3369	298597.8069	298597.8069

13.35	2.1247	0.3382	313907.2438	313907.2438
13.40	2.1327	0.3394	330001.6124	330001.6124
13.45	2.1406	0.3407	346921.1569	346921.1569
13.50	2.1486	0.3420	364708.1849	364708.1849
13.55	2.1565	0.3432	383407.1734	383407.1734
13.60	2.1645	0.3445	403064.8796	403064.8796
13.65	2.1725	0.3458	423730.4578	423730.4578
13.70	2.1804	0.3470	445455.5830	445455.5830
13.75	2.1884	0.3483	468294.5791	468294.5791
13.80	2.1963	0.3496	492304.5556	492304.5556
13.85	2.2043	0.3508	517545.5499	517545.5499
13.90	2.2123	0.3521	544080.6777	544080.6777
13.95	2.2202	0.3534	571976.2906	571976.2906
14.00	2.2282	0.3546	601302.1421	601302.1421
14.05	2.2361	0.3559	632131.5622	632131.5622
14.10	2.2441	0.3572	664541.6404	664541.6404
14.15	2.2520	0.3584	698613.4189	698613.4189
14.20	2.2600	0.3597	734432.0948	734432.0948
14.25	2.2680	0.3610	772087.2335	772087.2335
14.30	2.2759	0.3622	811672.9925	811672.9925
14.35	2.2839	0.3635	853288.3567	853288.3567
14.40	2.2918	0.3648	897037.3863	897037.3863
14.45	2.2998	0.3660	943029.4766	943029.4766
14.50	2.3077	0.3673	991379.6318	991379.6318
14.55	2.3157	0.3686	1042208.7524	1042208.7524
14.60	2.3237	0.3698	1095643.9378	1095643.9378
14.65	2.3316	0.3711	1151818.8037	1151818.8037
14.70	2.3396	0.3724	1210873.8166	1210873.8166
14.75	2.3475	0.3736	1272956.6448	1272956.6448
14.80	2.3555	0.3749	1338222.5276	1338222.5276
14.85	2.3635	0.3762	1406834.6638	1406834.6638
14.90	2.3714	0.3774	1478964.6194	1478964.6194
14.95	2.3794	0.3787	1554792.7569	1554792.7569
15.00	2.3873	0.3800	1634508.6862	1634508.6862
15.05	2.3953	0.3812	1718311.7386	1718311.7386
15.10	2.4032	0.3825	1806411.4654	1806411.4654
15.15	2.4112	0.3838	1899028.1617	1899028.1617
15.20	2.4192	0.3850	1996393.4176	1996393.4176
15.25	2.4271	0.3863	2098750.6969	2098750.6969
15.30	2.4351	0.3876	2206355.9462	2206355.9462
15.35	2.4430	0.3888	2319478.2345	2319478.2345
15.40	2.4510	0.3901	2438400.4266	2438400.4266
15.45	2.4589	0.3914	2563419.8899	2563419.8899
15.50	2.4669	0.3926	2694849.2381	2694849.2381
15.55	2.4749	0.3939	2833017.1131	2833017.1131
15.60	2.4828	0.3952	2978269.0066	2978269.0066
15.65	2.4908	0.3964	3130968.1239	3130968.1239
15.70	2.4987	0.3977	3291496.2923	3291496.2923
15.75	2.5067	0.3990	3460254.9159	3460254.9159
15.80	2.5146	0.4002	3637665.9792	3637665.9792
15.85	2.5226	0.4015	3824173.1022	3824173.1022
15.90	2.5306	0.4028	4020242.6499	4020242.6499
15.95	2.5385	0.4040	4226364.8982	4226364.8982
16.00	2.5465	0.4053	4443055.2603	4443055.2603
16.05	2.5544	0.4066	4670855.5747	4670855.5747
16.10	2.5624	0.4078	4910335.4610	4910335.4610

16.15	2.5704	0.4091	5162093.7437	5162093.7437
16.20	2.5783	0.4104	5426759.9495	5426759.9495
16.25	2.5863	0.4116	5704995.8819	5704995.8819
16.30	2.5942	0.4129	5997497.2756	5997497.2756
16.35	2.6022	0.4142	6304995.5364	6304995.5364
16.40	2.6101	0.4154	6628259.5702	6628259.5702
16.45	2.6181	0.4167	6968097.7055	6968097.7055
16.50	2.6261	0.4179	7325359.7145	7325359.7145
16.55	2.6340	0.4192	7700938.9384	7700938.9384
16.60	2.6420	0.4205	8095774.5209	8095774.5209
16.65	2.6499	0.4217	8510853.7566	8510853.7566
16.70	2.6579	0.4230	8947214.5598	8947214.5598
16.75	2.6658	0.4243	9405948.0598	9405948.0598
16.80	2.6738	0.4255	9888201.3292	9888201.3292
16.85	2.6818	0.4268	10395180.2526	10395180.2526
16.90	2.6897	0.4281	10928152.5412	10928152.5412
16.95	2.6977	0.4293	11488450.9033	11488450.9033
17.00	2.7056	0.4306	12077476.3768	12077476.3768
17.05	2.7136	0.4319	12696701.8321	12696701.8321
17.10	2.7215	0.4331	13347675.6554	13347675.6554
17.15	2.7295	0.4344	14032025.6203	14032025.6203
17.20	2.7375	0.4357	14751462.9582	14751462.9582
17.25	2.7454	0.4369	15507786.6372	15507786.6372
17.30	2.7534	0.4382	16302887.8605	16302887.8605
17.35	2.7613	0.4395	17138754.7952	17138754.7952
17.40	2.7693	0.4407	18017477.5441	18017477.5441
17.45	2.7773	0.4420	18941253.3717	18941253.3717
17.50	2.7852	0.4433	19912392.1988	19912392.1988
17.55	2.7932	0.4445	20933322.3783	20933322.3783
17.60	2.8011	0.4458	22006596.7674	22006596.7674
17.65	2.8091	0.4471	23134899.1112	23134899.1112
17.70	2.8170	0.4483	24321050.7532	24321050.7532
17.75	2.8250	0.4496	25568017.6903	25568017.6903
17.80	2.8330	0.4509	26878917.9894	26878917.9894
17.85	2.8409	0.4521	28257029.5842	28257029.5842
17.90	2.8489	0.4534	29705798.4713	29705798.4713
17.95	2.8568	0.4547	31228847.3276	31228847.3276
18.00	2.8648	0.4559	32829984.5687	32829984.5687
18.05	2.8727	0.4572	34513213.8715	34513213.8715
18.10	2.8807	0.4585	36282744.1862	36282744.1862
18.15	2.8887	0.4597	38143000.2601	38143000.2601
18.20	2.8966	0.4610	40098633.7025	40098633.7025
18.25	2.9046	0.4623	42154534.6156	42154534.6156
18.30	2.9125	0.4635	44315843.8226	44315843.8226
18.35	2.9205	0.4648	46587965.7222	46587965.7222
18.40	2.9285	0.4661	48976581.8027	48976581.8027
18.45	2.9364	0.4673	51487664.8485	51487664.8485
18.50	2.9444	0.4686	54127493.8751	54127493.8751
18.55	2.9523	0.4699	56902669.8302	56902669.8302
18.60	2.9603	0.4711	59820132.0991	59820132.0991
18.65	2.9682	0.4724	62887175.8572	62887175.8572
18.70	2.9762	0.4737	66111470.3114	66111470.3114
18.75	2.9842	0.4749	69501077.8773	69501077.8773
18.80	2.9921	0.4762	73064474.3393	73064474.3393
18.85	3.0001	0.4775	76810570.0449	76810570.0449
18.90	3.0080	0.4787	80748732.1843	80748732.1843

18.95	3.0160	0.4800	84888808.2144	84888808.2144
19.00	3.0239	0.4813	89241150.4816	89241150.4816
19.05	3.0319	0.4825	93816642.1086	93816642.1086

APPENDIX D

Definition of Terms

APPENDIX D

A SET OF TERMS, DEFINITIONS AND NOTATIONS FOR WIND GENERATED WATERWAVES AND THEIR ANALYSIS

1. Introduction.

The Commission believes that the adoption of standardized notation will greatly facilitate the exchange of information pertaining to waves and recommends that wherever possible, the notation presented in the following glossary be used. The current usage must change and adapt to progress, and researchers and engineers are encouraged to adequately define, with reference to the methods used in calculations, the notations used.

2. Definition of general terminology and dimensions.

The "mean water level" is the average water surface over a period of at least one year.

The "still water level" is the level of the water surface in the absence of wave activity.

The "mean record level" is the average water surface over the period of observation (for instance 20 min.).

(The definition of mean record level, which is of importance in the zero-crossing type of analysis, is not concise when significant variation in water surface elevation is caused by the tide within the duration of the record. Floating buoys tend to filter out this long period movement whereas staff gauges do not.)

A "wave record" is an analogical or digital recording of wave parameters over a *stated continuous interval*. In particular, a wave record may be an analogical or digital recording of the water surface elevation or pressure resulting from the passage of waves.

A "zero-crossing" is to be understood as the crossing of the mean record level by the water surface at that instant (after filtering tide effects).

A crest or maxima is an event where the water surface has zero slope, is preceded by a positive slope and followed by a negative slope.

A trough or minima is an event where the water surface has zero slope, is preceded by a negative slope and followed by a positive slope.

The subscript *Z* should be used to indicate zero-crossing waves.

The subscript *O* should be used to indicate deep water waves.

The subscript *b* should be used to indicate breaking waves.

The subscript *c* should be used to indicate crests or maxima.

The subscript *t* should be used to indicate troughs or minima.

The subscript *v* should be used to indicate visual observations.

The subscript *max* should be used for referring to the maximum value of the variable.

The overbar $\bar{}$ denotes an average value of the variable. (The use of the overbar $\bar{}$ to denote an average value may not be acceptable in some countries and the use of brackets $\langle \rangle$ or the subscript mean may be more acceptable.)

a This symbol should be used when referring to wave amplitude measured with respect to the mean record level.

H This symbol should be used when referring to wave height.

T This symbol should be used for referring to an interval of time related to the periodic property of waves.

L This symbol should be used for referring to wave length.

α This symbol to be used for the direction of wave propagation. It is the angle between true north and the direction from which the waves are coming. Clockwise direction is positive.

- Z** This symbol to be used for the vertical distance from an average value of the water surface to the bottom.

All variables and measurements should be dimensioned according to the S.I. system. In particular:

- space variable such as wave height, depth, etc., are given in meters;
- frequency as applied to gravity waves should be given in Hertz (Hz).

3. Parameters defined directly from a wave record.

- Z₁** The "mean water depth" is the vertical distance between the mean water level and the bottom. **Z₁** is always a positive quantity.
- Z₂** The "still water depth" is the vertical distance between the still water level and the bottom. **Z₂** is always a positive quantity.
- Z₃** The "mean record water depth" is the vertical distance between the mean record level and the bottom. **Z₃** is always a positive quantity.
- η** The vertical distance of the instantaneous water surface to the mean record level, positive is used for the upward direction.
- a_c** The crest amplitude is the vertical distance between the mean record level and a crest or maxima.
- a_{zc}** The zero-crossing crest amplitude is the maximum vertical distance between the mean record level and the maximum level that occurred between an upward and a following downward going zero crossing. **a_{zc}** is always a positive quantity.
- a_t** The trough amplitude is the vertical distance between the mean record level and a trough or minima.
- a_{zt}** The zero-crossing trough amplitude is the maximum vertical distance between the mean record level and the minimum level that occurred between a downward and a following upward going zero-crossing. **a_{zt}** is always a positive quantity.
- Y₁** The maximum wave level is the maximum zero-crossing crest amplitude observed in a record = **a_{zc,max}**
- Y₂** The minimum wave level is the maximum zero-crossing trough amplitude observed in a record. Note that **Y₂** is always positive and is = **a_{zt,max}**

- H** The "wave height" is the vertical distance between a crest and the immediately preceding trough.

- H_z** The zero up-crossing wave height is the sum of **a_{zc}** and the immediately preceding **a_{zt}**. (Confusion may exist between the use of Hz for Hertz and **H_z** for the zero-crossing wave height.)

- H_{max}** The maximum wave height is the maximum **H** as observed in a specified period of time, which should always be stated.

- H_{z,max}** The maximum zero up-crossing wave height is the maximum **H_z** as observed in a specified period of time, which should always be stated.

- T_z** The zero-crossing wave period is the interval of time between two adjacent downward going zero-crossings.

- T_{H_{z,max}}** The period of the maximum zero up-crossing wave height is the interval between the preceding and the following downward going zero-crossings of a maximum zero up-crossing wave height.

4. Statistical parameters (1) derived from 3.

- H_{n%}** The wave height exceedance is the value of **H** exceeded by *n*% of all waves occurring in a specified period. For example **H_{1%}** (20 min.) is the wave height that is exceeded by only 1% of all waves occurring in a 20 min. period of observation. In particular one may use **H_{50%}** the median wave height. In some countries, the notation **H_{n%}** is used to denote the average of the highest *n*% of the waves in a record. Care should be exercised to properly interpret the intended meaning in individual publications.

- H_{zn%}** The zero up-crossing wave height exceedance is the value of **H_z** that is exceeded by *n*% of all waves occurring in a specified period.

- H̄_{1/n}** The average of the highest 1/*n*th of the **H** values for a stated period of time. In some countries, the notation **H̄_{1/n}** is used to denote the wave height exceeded by 1/*n*th of the waves. Care should be taken to properly interpret the intended meaning in individual publications.

- H̄_{zn,1/n}** The average of the highest 1/*n*th of the **H_z** values for a stated period of time. In particular one may use **H̄_{zn,1/8}** (20 min.).

(1) **H_{n%}**, **H_{zn%}**, **H̄_{1/n}** and **H̄_{zn,1/n}** are tentative and not definitive proposals of the Commission.

$\bar{T}_z$ The zero-crossing wave period is the average of zero-crossing intervals as obtained by dividing the record duration by the number of times the water elevation crosses the mean record level in one direction.

$\bar{T}_c$ The average crest period is the time obtained by dividing the record duration by the total number of crests in this record.

ϵ_T The spectral width parameter (Broadness factor) defined by $\epsilon_T^2 = 1 - (\bar{T}_c/\bar{T}_z)^2$.

$p(x)$ The probability density function of a wave parameter x , such as height or period.

$P(x)$ The distribution function of a wave parameter x and is known as $P(x) = \int_{-\infty}^x p(\lambda) \cdot d\lambda$.

5. Parameters derived from the variance spectrum analysis.

f_p The peak frequency is the frequency at which the maximum variance spectral density occurs.

T_p The peak period $= 1/f_p$.

$S(f)$ The variance spectral density function of a wave record is the density distribution of the variance η as a function of frequency.

$S(f, \alpha)$ The directional variance spectral density of a wave record is the density distribution of the variance η as a function of frequency and direction.

m_n The n^{th} moment of the variance spectral density function. $m_n = \int_a^b f^n S(f) df$. Typically $a = 0$ $b = \infty$.

σ The root mean square value is the square root of the variance or the average squared displacement of the water surface from the mean record level $\sigma^2 = \bar{\eta}^2 = m_2$.

H_{m_0} The characteristic wave height $= 4\sigma$ for a stated period of time.

$T_{m_{a,b}}$ The length of time defined by two spectral moments m_a and m_b . In particular, one may use the "average period" defined as m_0/m_1 or m_{-1}/m_0 .

ϵ_s The spectral width parameter defined by
$$\epsilon_s^2 = \frac{m_0 \cdot m_4 - m_2^2}{m_0 \cdot m_4}$$

6. Parameters derived from visual observations.

H_v The wave height as estimated from visual observation.

T_v The wave period as obtained visually.

7. Significant wave height.

The current use of this term, significant wave height, is confusing. There appear to be 3 common concepts of significant wave height:

- a) the wave height parameter as computed from the RMS-value of the record;
- b) the average of the highest one third of the "wave heights" obtained autographically; or
- c) the visually estimated wave height following W.M.O. practices.

As noted in the above, the following three definitions are recommended:

H_{m_0} The characteristic wave height $= 4\sigma$ for a stated period of time.

$H_{z,1/3}$ (or H_z) The average of the highest one third of the zero up-crossing wave heights for a stated period of time.

H_v The wave height as estimated from visual observation.